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AUTOPLASTIC BONE SURGERY

BY

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LEA & FEBIGER
PHILADELPHIA AND NEW YORK
1916

HARVARD MEDICAL SCHOOL
Surgical Library Book Fund
24 May 1916

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PREFACE.

THE authors have endeavored in the following discussion of facts and theories to present them with simplicity and lucidity. One soon recognizes after a careful review of the voluminous literature of the last few years the difficulty of justly estimating the value of conflicting opinions, but a judicious selection from this vast material is the most important duty of the writer. In seeking the ultimate truth in any field of human endeavor one must often be satisfied with a suspension of judgment; or he may, as in the present problem, record the uncorrelated deductions from experimental and clinical researches, so that, unbiased, the reader can draw his own conclusions. The structural complexity of the tissues chiefly considered in this work tends further to render difficult a correct interpretation of their lesions.

In certain chapters the deductions of the authors, which in many cases differ from those expressed in the literature, are based primarily upon the histopathological study and analysis of tissues removed from experimental animals at varying stages of the reparative process. The experimentation not only includes such problems as are connected with the regeneration of osseous tissue, but problems in technic, mechanics, and many minor questions in this difficult field of surgical science. The resulting experimental data, which were considered of sufficient clinical importance, have been incorporated in the text. The more practical part of this work has been done during the past two years directly in connection with its clinical application. The chapters upon the autoplastic bone transplant reflect the authors' personal observations of many cases in which this method of treatment was used, and the clinical deductions are based upon their personal operative experience. The patients have been under röntgenological observation, at intervals of three months, for varying periods of time up to two years.

While it is recognized that the transplantation of bone is not an entirely new procedure, its extensive application has only been made possible since the advent of asepsis. All reliable methods of obtaining asepsis in bone surgery must withstand an unbiased and detailed scrutiny. The demand for a logical presentation of the subject matter shows how greatly a work of this character is needed. It was with a keen appreciation of this demand that the present volume was undertaken.

Repair of intractable, recent, simple fractures by autoplastic transplantation of bone is fully described in Chapter VI. It is hoped that the methods herein described will largely replace the use of metallic foreign bodies for fixation in fractures of this character which require open operation.

Chapters I, II, and III were written by Dr. Smith. Chapters IV to XI, inclusive, were written by Dr. Davison. The photomicrographs and the majority of röntgenograms were made in the Laboratory of Clinical Pathology of the University Hospital. The authors are indebted to Dr. E. S. Blaine, of Cook County Hospital, to Dr. Adolph Hartung, of the Laboratory of the Medical College of the University of Illinois, for other röntgenograms, to Mrs. N. M. Frain for the excellent drawings, and to Mr. Hawes for the many excellent photographic reproductions. Illustrations which have been very courteously loaned will find proper acknowledgment where they appear. The authors wish also to acknowledge the courtesy of Dr. E. R. Le Count for the postmortem specimens which have been sectioned and reported on pages 93 and 208. They desire to thank their colleagues for patients referred, and their internes for assistance in the clinical part of the work.

C. D.
F. D. S.

CHICAGO, ILLINOIS, January, 1916.

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AUTOPLASTIC BONE SURGERY.

CHAPTER I.

THE TRANSPLANTATION OF BONE.

EARLY HISTORY.

SUCCESSFUL transplantation of bone in human beings has been accomplished in the East for centuries. It was later introduced into Italy and thence into Europe. In the early history of the transplantation of bone, heteroplastic grafting of bone from animals was more extensively employed and with many reported successful cases. The earliest report dates back to the year 1682. During this year is found the following decree against Jobi Meekren: "Chirurgicum ossis cranii fragmentum anferre jussit, sique, curatione alia adhibita excommunicationis vim effugit. Jobi a Meekren observat medico-chirurg."[1] Jobi Meekren transplanted a piece of the skull of a dog into the defect in the skull of a soldier. This was probably the earliest successful case of heteroplastic transplantation. In those early days of superstition when the Church ruled all it surveyed, Jobi Meekren was forced to remove the implanted bone under the ban of excommunication from the Church which refused to recognize such a monumental work and referred to it as "an unchristian" method of treatment.

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[1] Ex Beligico in lat. translation of A. Blasio, Amsterdami, 1682, pp. 6 and 7.

From time to time each successive school or generation of medicine has undertaken to solve the mysteries involved in the transplantation of bone. Its application to the present time has been more or less mechanical and not based upon the subsequent pathological changes. Many absurd operations have been performed because of a lack of knowledge of the laws bearing upon the subject.

It is possible, under certain specified circumstances, to transplant bone and for this bone to retain its vitality and proliferate in its new situation. This can be accomplished not only (*a*) in connection with bone removed from a given locality to another position in the same individual but (*b*) with bone removed from another individual of the same species and (*c*) on rare occasions even with bone removed from another species entirely.

TERMINOLOGY.

During the present new era of bone surgery a voluminous literature has appeared with a tendency to use terms somewhat loosely. Implantation is a group name and includes "all processes of inserting solid matter into the tissues of a living animal, whether living or dead tissue, or inert material of animal origin." Transplantation refers only to the insertion of living tissue—in this case, bone. Such transplantation is called autoplastic[1] when bone from the same individual is transplanted, the same procedure is also known as isoplastic transplantation; while homoplastic transplantation refers to transplantation of bone of another individual but of the same species; it is known as heteroplastic transplantation when bone of another species is utilized. The unit of the transplantation is called either the osteoplastid or the heteroplastid. When bone is transplanted into bone it is known as homotopic transplantation, but as heterotopic when bone is transplanted into tissue other than bone, such as muscle or omentum, etc. Replantation or reimplantation is used to designate the replacement of an organ or tissue after removal (*e. g.*, replacing osteoplastic flap in the skull). Certain terms are employed to designate different mechanical methods for the utilization of bone transplantation, such as peg and medullary transplant.

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[1] Autogenous transplantation is a misnomer and should not be employed.

BONE WITH OR WITHOUT PERIOSTEUM.

In the transplantation of bone, either homotopic or heterotopic, the factors entering into the consideration will depend upon the ultimate desired results. If it is desired to merely fill in a space for cosmetic purposes, the skill with which the transplant with its varying constituents is obtained will not be as exacting as if the transplant was primarily expected to completely immobilize and maintain proper coaptation of the fracture, and secondarily to form an osseous union with its surrounding osseous tissue. The bed into which the transplant is placed will make certain demands upon the graft which will require either the presence or absence of certain of its constituents. In this connection particularly, it must be remembered that one surface of either the periosteum or the endosteum is non-osteogenetic. A few failures from mere fibrous union have been observed, due to the lack of respect for this property of both the periosteum and the endosteum. Certainly a transplant with its adjacent periosteum intact should never be placed into the medullary cavity of a bone, even though its surface had been previously curetted, and expect complete osseous union. Moreover, a periosteal-free transplant should not be used when exposed bone of the transplant is in contact with the surrounding and adjacent muscle tissue; if it is necessary to use a periosteal-free transplant, under such conditions, transplanted fascia is capable of assuming both the nutritional and limiting function of the periosteum.

While a transplant of limited size is capable of maintaining a greater portion of its inherent vitality, its ability to retain this vitality is greatly diminished in the presence of bacterial toxins and other protoplasmic poisons as bichloride of mercury, alcohol, and other so-called antiseptic solutions. Many living tissues with their adaptable blood supply and under their well-regulated neurotrophic guidance, cannot always resist such insult. Therefore, the presence of such harmful agents in the present state of our knowledge of such devitalizing compounds is nothing more or less than courting failure. More can be expected of any graft, the bed of which is composed of a full quota of constituents of the graft, as endosteum, cortical bone and periosteum approximating their corresponding prototype in the host.

AUTOPLASTIC TRANSPLANTATION NECESSARY FOR ALL PRACTICAL WORK.

Under the limitation of our knowledge of transplantation at the present time, isoplastic or autoplastic transplantation must by all means be given the foremost consideration, and a fresh, living osteoplastid used. Only second to this method may be considered that procedure in which the graft is obtained from another individual of the same species. Homoplastic grafts are not always obtainable when they are most desirable, and moreover, even by exercising the utmost attention, the possibility of transmitting a disease from the donor to the host is a factor which is not to be considered lightly. Under exceptional and most favorable circumstances, not definitely known at the present time, and only occassionally can a heteroplastic graft be expected to be treated "kindly" by its host. In the great majority of instances the heteroplastid is received by the host, like any foreign element, being destroyed by the macrocytes. The living osteoplastid from a species, entirely foreign to the host, when transplanted into man (from lower animals) usually undergoes necrosis and in the case of an infection either is completely absorbed or will slough out. In case of bone transplants, this is a slow and long-drawn-out process, and while clinically the end-results are all that could be expected, histologically variable degrees of absorption will be found. If the process is not complicated by an infection, the transplant may become encapsulated or absorbed and its place taken by organizing granulation tissue from its surrounding traumatized walls.

It is probable that not in the distant future, as Tuffier hopes, "some chemical which will protect the graft from an attack by the macrocytes" will be discovered.

The subject of transplantation of bone has been intimately interwoven with the discussion and experimentation upon the regeneration of bone *per se* and the value of its various constituents in the process of regeneration.

CHAPTER II.

THE PERIOSTEAL REGENERATION OF BONE.

INTRODUCTION.

DURING the past two centuries the relation of the periosteum to the regeneration of bone has been a very much debated subject. The very earliest observations upon this subject were those of Clopton Havers (1692), Antoine de Heyde (1684), Duhamel du Monceau (1739–1743) and Troja (1761). Clopton Havers, after whom the vascular canals of compact bone were named, describes the periosteum, from a purely anatomical and microscopic point of view, as merely a connective-tissue membrane, limiting and vascular in its function. The discussion, from experimentation upon animals, began with the observations of Duhamel du Monceau, the French naturalist, who in 1739, advanced the theory that the ultimate osseous tissue was derived from the periosteum. The experimental data upon which this statement was based is the oft-quoted classical ring experiment. By placing a silver ring underneath the periosteum in a living animal he found after examination, some weeks later, that osseous tissue had completely surrounded the ring. From this he concluded that the new bone was derived from the periosteum and that the original bone has nothing to do with the formation of the new bone. Later, in 1743, he observed that the periosteum became succulent and thickened around a fracture, and by pushing this new bone in among the fragments, it forms callus.

Osteogenetic properties were attributed to the periosteum by Dupuytren and Cruveilhier; while Virchow, in 1858, states that the bone cells are derived from the periosteum by a process of metaplasia. Gegenbauer, in 1864, confirmed these views and gave the term osteoblast to the cells in the osteogenetic or "cambium" layer of the periosteum.

Duhamel's theory was ably supported by Ollier, in 1858, who was one of the foremost earlier investigators in this field of research. He concluded, from his excellent experimental and accurate observations, that all transplanted bone, including the periosteum, retains its inherent vitality and attributed especial histogenetic properties to the osteoblastic layer of the periosteum. For the successful transplantation of bone he gave preference to living bone which is covered with the osteogenetic membrane. He went much farther, however, and added another function to the periosteum besides its inherent power of regeneration of bone and concluded that bone denuded of its periosteum would undergo necrosis and would be treated by the host as a foreign body, eventually becoming completely absorbed. After absorption it was replaced only because of the direct contact with the osteogenetic walls of the host.

The conclusions of Barth (1894–1908) are directly opposed to those of Ollier and Duhamel. From his animal experimentation on the transplantation of osseous tissue, he concludes that all transplanted bone, whether periosteal-free or covered completely with periosteum, eventually dies and that bone regenerated from the living osseous tissue of the immediate adjacent bed. Since the publication of Barth, in 1896, there exists a considerable difference of opinion in the literature concerning the periosteal regeneration of bone.

With the advent of the workingman's compensation law and the perfection of the high-power Röntgen transformer, and consequently its more general employment in the diagnosis of position of fractured bones, it was readily recognized that only occasionally anatomical accuracy of coaptation of the fragments is attained by the application of external splints. These two important factors enforced the surgeon to the employment of the transplantation of bone to secure more accurate apposition of the fragments. The early and conflicting experiments concerning the value of the periosteum in the transplantation of bone aroused a lively discussion which assumed greater proportions as the transplantation of bone became more popular, since it raised a vital question as to just how much attention should be given to the periosteum. A keen interest in these problems has lead to extensive experimentation and many ardent followers both pro and con.

Since the problems under discussion can hardly be considered closed questions, the differing opinions must be given due attention. Hence a brief résumé of the important literature will be given, no attempt being made to discuss any conclusions, as it is desired to present the problems later in the light of my own experimentation.

LITERATURE.

Frangenheim (1910) ascribes a limited influence to the periosteum in producing bone but admits that it plays a relatively insignificant part in the process of regeneration of bone.

Macewen (1912) in his book on *The Growth of Bone*, summarizes the function of the periosteum as follows: "The periosteum is of great use in limiting within specific boundaries the distribution of the osteoblasts and preventing them during the evolutionary period from being scattered into the soft tissues, where their presence would be prejudicial to the function of these parts. In the loose areolar tissue existing between the periosteum and the bone, the osteoblasts find nutriment for their growth and space to regenerate, free from undue pressure. While not underestimating the periosteum as a limiting and protecting membrane, of great use in physiological and pathological conditions, there are no data at the present time to indicate it can, of itself, secrete or reproduce bone. It has no osteogenetic function." These views as yet can hardly be accepted. Adami has expressed the general consensus of opinion very tersely in a foot-note in the last edition of his *Pathology* as follows: "We are not as yet prepared to accept those views, holding the opinion that those observers have dealt only with the outer fibrous layer, and not with what may be termed the 'cambium' or mother-cell layer in immediate contact with the actual bone."

Murphy (1912) believes that bone free from periosteum is always absorbed in heterotopic transplantation.

Baschkirzew and Petrow (1911) in a very interesting article concerning the regeneration of bone, admit that the periosteum is of value in the clinical application of bone transplantation, not because of its power to regenerate bone, but rather because of its aid in directing bone growth, and serves to protect new bone. They also state that new bone is produced by periosteum, only sooner or later to be absorbed completely.

Lobenhoffer (1910) from his experiments concludes that in transplantation of bone covered with periosteum, the bone transplant dies completely, but that the periosteum retains its inherent vitality.

In summarizing the work of Axhausen (1908–1911) it can readily be seen that he assumes the position that neither bone alone nor periosteum *per se* is osteogenetic; some of the bone dies, but a portion of it retains its vitality; periosteum and marrow substance remain alive and produce new bone; there is no material difference in homotopic transplantation of bone, whether the transplant is dead or alive, or whether it is or is not periosteal-free, but the chances are far more favorable of successful regeneration if it retains its vitality and is covered with periosteum.

Trinci found in his experiments on rabbits and dogs that in free periosteal transplantation, bone was formed from the periosteum. He also emphasizes the importance of blood-clot and bone particles as a stimulating material for bone formation from the lower layer of the periosteum; a lack of these stimulating substances is associated with a decreased activity in proliferating power. He refers to an article by Bonomme in which the same results are recorded.

Carrel (1912) was able to reproduce bone from periosteum after it had been grown in his special medium. The artificially growing periosteum was transplanted into subcutaneous tissue and led to the production of bone.

Pochhammer (1912) studied the regeneration of bone by the heterotopic transplantation of scrapings from the cambium layer of the periosteum and obtained negative results. But on repeating the experiments with teased pieces of periosteum he observed bone regeneration in 15 per cent. of the 8 cases. However, when a mixture of scrapings from the periosteum and outer surface of the bone was transplanted into muscle, small nodules of bone were observed as early as ten to fourteen days.

Berthiers (1894) in his studies on myositis ossificans, transplanted periosteum into muscle with practically the same results.

Jokio (1912) observed bone formation in heterotopic transplantation of an emulsion of periosteum injected subcutaneously or intramuscullary. He also stated that if fresh blood was injected there was no increase in bone formation but there was increased proliferation when fibrin was substituted for blood. Nahahara and Dilger reported in a previous publication very similar results.

Hass (1913) concluded that the periosteum, especially in the presence of blood-clot, has the power to regenerate bone; that the regeneration of bone was never found excepting when periosteum was present. In a more recent article (1914) he states that it is apparent from his studies that the periosteum is very actively concerned in the regeneration of bone; there is at first a proliferation of all its cellular elements to reproduce a cartilaginous material, which is in turn transformed into bone.

Schepelmann (1913) finds that the periosteum when transplanted into the omentum, mesentery, spleen and liver regenerated persistent new bone, and he emphasizes the importance of vascularity, integrity of the cell, and the use of the entire periosteum.

Ryerson (1913) attacking the problem by an entirely new method, concludes from röntgenoscopic study of the early changes which take place in fractures, that "there is no regeneration from the periosteum because he could not see any new bone formed in the osteo-periosteal angle where the periosteum is stripped up from the cortex."

Gallie and Robertson (1914) conclude from their experiments that periosteum is unable to regenerate bone. Their experiments consisted in separating the periosteum from the cortical bone by some metallic substance such as tin-foil and later examining for evidence of bone formation from the periosteum.

McWilliams (1914) states that the osteogenetic properties of the periosteum are not of much importance, but assigns a new function to the periosteum, and this is "its power to increase the blood supply." The periosteum renders the transplant more easily permeable by surrounding capillaries, thus insuring the early establishment of an adequate circulation through it.

Grooves (1914) concludes from his experimental studies, in a very extensive article, that the periosteum has no osteogenetic function.

Mayer and Wehner (1914) present in their studies on the regeneration and transplantation of bone conclusive evidence against the theory of Macewen and his followers. They observed that periosteum from a very young animal when transplanted into muscle possesses the property of regenerating bone; also, that periosteum after subperiosteal resection of the ribs possesses the property of regenerating bone. They also ascribe a like function of proliferation to the endosteum.

Nichols, writing on osteomyelitis, says: "When periosteum retains its vitality, it will regenerate new bone, but if the periosteum sloughs there will be no regeneration. Success depends upon mechanics and physiology, osteoconductivity and osteogenesis. Bone alone is mechanically efficient, but physiologically deficient; periosteum alone or with its attached osteoblasts is physiologically efficient and mechanically deficient."

After a survey of the foregoing abstracts and a study of the methods of experimentation, the following questions naturally arise: What constitutes the periosteum? Have all investigators included or excluded the same cellular constituents? Are the constituent components of the periosteum constant or are they subject to extensive variation, either numerically or in arrangement and type of its cellular elements? Much confusion exists as to the exact components of the periosteum. For this reason a detailed account of the origin, development and anatomy, both gross and histological, of the periosteum will be given.

DEVELOPMENT OF THE PERIOSTEUM.

Early during fetal development, many cells of the somatic and splanchnic mesoderm undergo a metamorphosis into embryonic connective tissue, known as mesenchyme. The mesenchyme is the forerunner of connective tissue, and is intimately associated with the histogenesis of the various organs of the body as well as the formation of definite membranes, cords or solid masses, etc., such as fasciæ, tendons, ligaments, and cartilage. It is from these blastemal cells that the periosteum is ultimately developed.

The development of the periosteum is dependent upon the type of bone which it envelops. Bone may be derived directly from fibrous tissue, in which case it is known as intramembranous or metaplastic formation, or it may be formed in cartilage as an intermediate stage and then is known as endochondral or neoplastic bone formation. Bone is always preformed in either fibrous tissue or cartilage.

DEVELOPMENT OF THE PERIOSTEUM IN METAPLASTIC BONE FORMATION.—In the metaplastic or intramembranous development of bone, when the inherent organic power of the organism stimulates the fibrous tissue to become differentiated into osseous tissue, certain cells known as osteoblasts deposit calcium salts in the fibrous tissue matrix, forming a network of bony spicules. These spicules, as development continues, increase in thickness and extend farther out, radiating in all directions into the connective-tissue matrix. Sometime later the cells of the mesenchyme, which are directly adjacent to the reticular plate of bone previously produced, are seen to condense and form a "stout membrane." This membrane becomes what is known as the periosteum. By the time the periosteum becomes recognizable as a distinctly condensed membrane, a layer of osteoblasts arrange themselves in a more or less definite manner between the periosteum and the developing bone.

DEVELOPMENT OF THE PERIOSTEUM IN ENDOCHONDRAL BONE FORMATION.—In this type of bone development the preformed bone fundaments exist in hyaline cartilage. This cartilage is surrounded by a fibro-cellular membrane—the perichondrium. Ossification in cartilage is initiated in one or several circumscribed areas, known as ossification centres. While certain changes are taking place in the cellular elements of the cartilage, there is deposited a thin layer of bone by the perichondrium in precisely the same manner as takes place in the metaplastic formation of bone. The perichondrium becomes the periosteum and is directly derived from the mesenchyme.

It is readily seen that along a definite line there is compact bone deposited on one side and dense fibrous connective tissue on the other side, while separating these dissimilar tissues there are several layers of actively vegetative cells, the osteoblasts. Bone is a direct product of osteoblastic activity, while the periosteum is the result of the tissue reaction produced by a direct invasion of highly differentiated cells into a less differentiated cellular structure.

ANATOMY OF THE PERIOSTEUM.

The periosteum is a dense fibrous tissue membrane completely covering the outer surface of compact bone except where bone is covered by cartilage, as over the articular surfaces. The periosteum is reflected upon the surface of tendons, becoming a part of its developing sheath at the situation of the tendinous attachments to the bone. Many fine capillaries pass from the under surface of the periosteum into the compact bone through Volkman's canals. When the periosteum is stripped from living bone, many bleeding-points will be observed indicating the site of entrance of the capillaries into the bone. This dense membrane is firmly adherent to the surface of the compact bone, due to fasciculæ of fibrous tissue passing from the periosteum into the bone, piercing it at right angles to its surface. These are the fibers of Sharpey. They do not penetrate into the bone deeper than the circumferential lamellæ—bone formed by the activity of the periosseous osteogenetic layer of cells. Blood-vessels from the periosteum penetrate the compact, cortical bone and reach the marrow substance, communicating with branches from the nutrient artery. The periosteum also furnishes the blood supply to the cancellous bone, the branches of which ramify in the cavities of the spongy bone.

The periosteum is a very important factor in maintaining the life of the bone; however, that it is not essential is proved and conceded. The blood supply of bone is derived from two sources, *i. e.*, (*a*) mainly from the nutrient arteries and (*b*) from the arterial blood supply of the periosteum. The capillaries of the periosteum at short intervals, contribute small arterioles to the underlying compact bone which traverse the Haversian canals, ramify in the interstices of the osseous tissue, principally nourishing the circumferential lamellæ of bone. In case of suppuration thrombosis of the periosteal capillaries occurs and extends into the cortical bone, diminishing the supply of pabulum to the part with subsequent necrosis. However, in such cases, the blood supply may be partly assumed by the endosteal vessels. There is no doubt that the ability of bone to maintain its vitality when it is deprived of its periosteal blood supply, as in suppurative conditions, is dependent upon the blood supply in the circumferential lamellæ being derived from the endosteal capillaries.

HISTOLOGY OF THE PERIOSTEUM.

The periosteum can be conveniently divided into two portions, the fibrous tissue membrane or capsule and the periosseous osteogenetic cellular layer. It is very doubtful as to whether the latter is a part of the periosteum, or more properly to be considered as a part of the compact bone. The fibrous tissue membrane is nearly constant in its histological components while the periosseous osteogenetic layer differs in its component constituents at different stages of development of the body, and is subject to variation under the influence of traumatic, toxic, chemical or mechanical causes. During fetal life and the stage of developing bone, the cellular elements of the periosseous layer are greatly increased numerically. However, in adult bone or after the growth of bone has ceased, the periosseous layer diminishes to a few remnants of its former structure. The periosseous layer is intimately associated with the metabolic activity of the subjacent osseous tissue; its component cellular elements increase or decrease numerically directly with the physiological or pathological variation in the metabolic demands of the osseous tissue which it covers. In adult bone its function is slightly different from that of young bone and extremely at a variance with that of irritated or infected bone.

In studying the histological elements of the periosteum, it is not sufficient to merely examine the stripped membrane, but it must be studied in its proper relation to compact bone. If this method is the one employed, the difficulty immediately arises as to exactly where to draw the line of separation between the periosteum and its underlying structures. This difficulty is readily observed in studying sections taken from the centre of a long bone with its adjacent periosteum intact (as in Fig. 1).

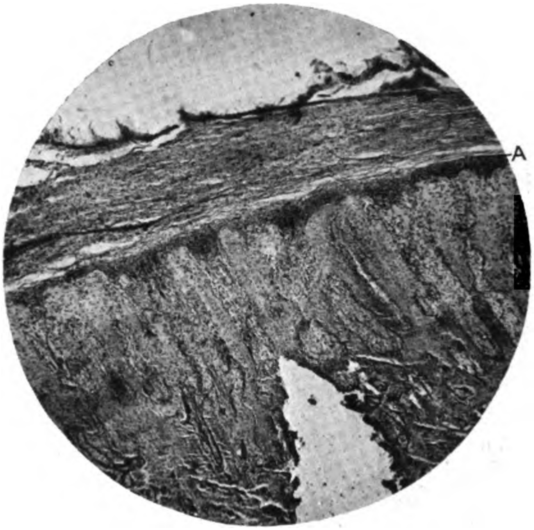

FIG. 1.—Cross-section of the femur showing the periosseous osteogenetic layer and its intimate relationship to the underlying osseous tissue. Low-power objective.

At once, it is seen, that microscopically there is no demonstrable line of separation between the periosteum, periosseous osteogenetic layer or subjacent, compact bone. Occasionally there is an artificially produced line of separation during the sectioning process, but this varies and with proper fixing methods does not occur. From a study of the intact periosteum, the external fibrous tissue membrane consists of layers of interlacing bundles of dense fibrous connective tissue and large capillaries, the branches of which penetrate into the subjacent cortical bone. Directly beneath this outer fibrous coat and in immediate contact with it, is a firm fibro-elastic stratum which varies with the age of the bone. In adult bone it is closely attached and firmly adherent to the surface of the bone. Between this fibro-elastic stratum and the cortical bone are seen many layers of cells, this is the *periosseous osteogenetic cellular layer.* In young, developing bone it consists of many minute capillaries, numerous small cells (the osteoblasts), and fine connective-tissue fibrils. The cellular elements are easily divided into two distinct types of cells, an outer layer of cells with plate-like nuclei closely packed together and an inner layer containing small oval nuclei. In the section referred too above it will be seen that the cells of this layer project into spaces between compact bone, not merely a few cells, but many actively vegetative cells pass down deep into the cortical bone; being typically osteoblastic in type on the surface, they become more and more differentiated the farther into the cortical bone they pierce, finally losing their complete identity. It is these projections of compact bone into the adjacent periosseous layer which makes

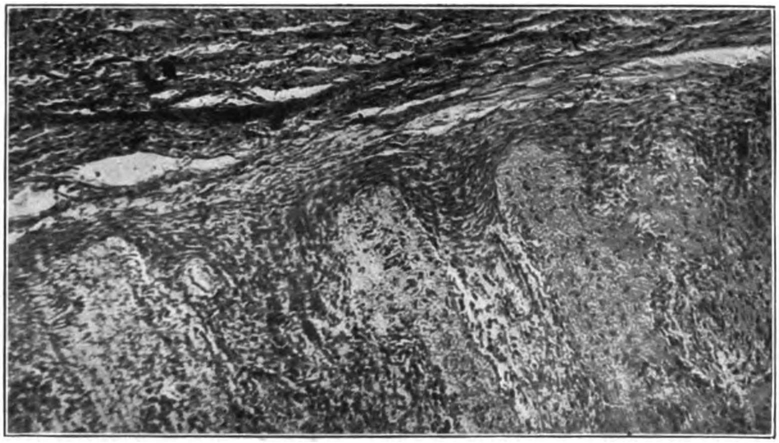

FIG. 2.—Same as Fig. 1, showing periosseous osteogenetic layer under the high-power objective.

it difficult to see just how a subperiosteal resection may be performed with any degree of certainty that plates of compact bone have not been removed and do not remain adherent to the periosteum. The mere fact that there is no macroscopic evidence of cortical bone plates is no scientific criterion from which to draw future conclusions.

THE PERIOSTEUM FROM A SURGICAL POINT OF VIEW.

The term periosteum, as employed surgically, is understood as that membrane which remains after a careful subperiosteal resection of the underlying bone, especial care being exercised that no bone elements are allowed to remain adhering to the periosteum. As such, is it a constantly definite structure containing the same histological elements in the same numerical ratio? If it is not a constant membrane, then transplantation experiments designed to prove either its capacity to regenerate or not regenerate bone are unreliable and certainly not suitable for scientific deductions. Moreover, it is definitely known that the periosteum in different stages of bone development is composed of cellular elements existing in varying numerical proportion, subject to increase by either toxic, chemical, or mechanical causes. Notwithstanding the facts that all the minute details of transplantation are performed with the greatest accuracy, one varying structure, as the periosteum, is sufficient to produce end-results at a greater or less variance with each other, even so far as absolutely contradictory results.

The histological components of the stripped periosteum, vary with the method of stripping, definitely proving that there is no distinct or constant line of cleavage. Periosteum removed slowly will contain cellular elements in greater or less proportion than periosteum that has been removed with a quick stroke and a sharp periosteotome.

In all animal experimentation, in which periosteum is transplanted into soft parts, it must be remembered that as a generally accepted axiom, tissues transplanted into tissues, upon which no functional demands are made, will not regenerate and grow but rather will become atrophic and later undergo complete absorption. To this must be added the importance of the variability of the periosteum which from the surgical point of view may be extremely marked. With these two primary factors clearly in mind it is possible to formulate some idea of the osteogenetic properties of the periosteum. In one set of experiments, several associates removed the periosteum for transplantation from different animals of the same species, standard adult rabbits of the same age being selected. The subperiosteal resections were performed with as nearly identical technic as it is possible for different individuals. All the transplants thus obtained were transplanted by one experimenter, employing the same identical technic, and the results obtained were absolutely contradictory to each other. This clearly demonstrates the importance of a third factor in the performance of subperiosteal resection, *i. e.*, that the histogenetic components of the stripped periosteum are dependent upon a varying personal factor.

It is possible to vary the end-results according to certain specific technic, contingent upon the performance of the subperiosteal resections; subperiosteal resections performed with a fairly sharp periosteotome and with a quick, stripping action will regenerate bone in a greater percentage of cases if young animals are used than if fully developed, adult animals are employed. Likewise a greater percentage of positive results will be obtained with periosteum which has been stripped slowly and with an elevating action of the periosteotome than when the periosteum is quickly torn loose from the compact, cortical bone. A very large percentage of positive results can be obtained by transplanting very small strips of periosteum, resected from very young animals. Fibrin is a very active stimulant to osteoblastic proliferation.

COMPLETE REGENERATION OF THE DIAPHYSIS AFTER SUBPERIOSTEAL RESECTION.

After a subperiosteal resection of a shaft of a bone, either subsequent to periosteomyelitis or merely to obtain a medullary transplant (from the shaft of the fibula), invariably the entire diaphysis will regenerate from the periosteum and completely fill in the gap. In a boy, fourteen years of age, three inches of the fibula was resected from its periosteal sheath, to be used as a medullary transplant in a fracture of the tibia of the same leg. Ten weeks following the resection compact bone completely filled in the periosteal tube and at the end of fourteen weeks a new medullary cavity was being formed through the regenerated bone. These changes are shown in the following series of röntgenograms (Figs. 3, 4, and 5).

Complete regeneration of bone following subperiosteal resection, both experimentally and clinically, is a proved and accepted fact.

SUMMARY.

The periosteum consists of the fibrous tissue capsule surrounding the bones and as such has no osteogenetic properties, but like the capsule of the liver or other organs, is merely the resultant tissue reaction made by less differentiated cells against the invasion of cells of a more highly specialized type. Beneath the periosteum is found a very cellular structure composed of many small cells and is a part of the bone proper and not of the overlying fibrous tissue capsule. This

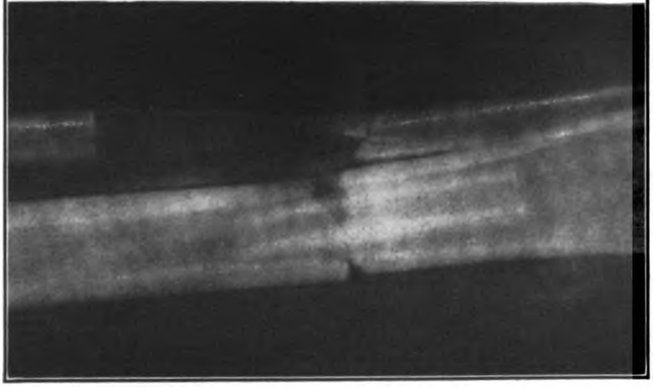

FIG. 3.—Primary defect.

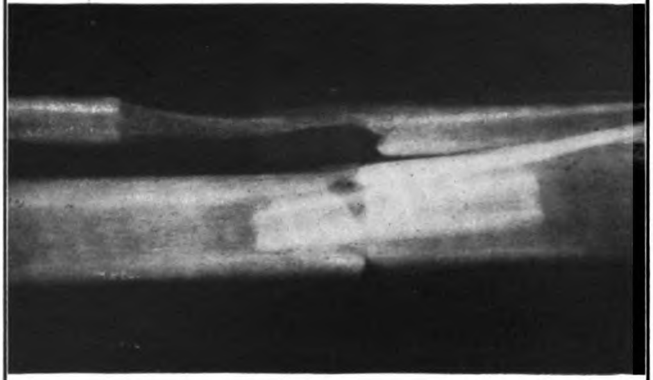

FIG. 4—Beginning regeneration.

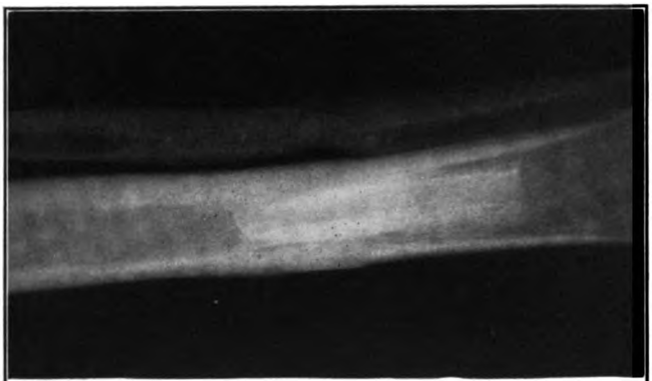

FIG. 5.—Diaphysis complete.

FIGS. 3, 4, and 5.—Röntgenograms illustrating complete regeneration of the fibula after removal of a segment 8 cm. in length.

cellular layer is called the "periosseous osteogenetic layer," since by virtue of its cellular constituents it can, when stimulated to proliferation, produce bone. This osteogenetic layer is present before the surrounding mesenchyme undergoes a condensation into a "stout membrane"—the periosteum.

From a surgical point of view, the subperiosteal resection of the periosteum may or may not remove with the periosteum any of the osteogenetic cellular constituents of the periosseous layer. The removal of the osteogenetic cells is dependent upon the individual technic employed, and macroscopic evidence is no scientific criterion as to their presence or absence.

Regeneration of bone from transplanted periosteum cannot be accomplished without the presence of some of the cellular components of the periosseous osteogenetic layer.

CHAPTER III.

REGENERATION OF BONE.

INTRODUCTION.

THE transplantation of bone, its regeneration and its ultimate fate, subsequent to its transplantation in the host have been subjects which have provoked considerable discussion and experimentation during the past century. Clinically the latter two questions, the regeneration of bone and the ultimate fate of the osseous transplant in the host are of very little importance, since any method of therapeusis which under proper indications aids in the ultimate restoration of the function of the part has fulfilled the required demands. However, without a thorough understanding of the conditions under which the osseous transplant is most favorably received by the host would lead to many failures. Failures may be due to the improper treatment of the osteoplastid, either mechanical, chemical or thermic, while an adequate appreciation of these demands is closely connected with its histogenesis. The histogenesis of bone is a very interesting problem since bone may be derived from the periosteum or from bone *per se*, or may be formed in the walls of the bloodvessels and other structures (as the choroid coat of the eye) ordinarily not the situation of such immutable tissue. Moreover, since the observations of Gegenbauer, in 1864, concerning the specific cellular forerunners of bone—the osteoblast—the origin of heterotopic bone formation has been an important problem, since the new bone formed must either be derived from specific bone-forming cells, in which case they must be carried from place to place by the blood stream or else, the only alternate, we must accept the metaplastic theory of Virchow and lately more thoroughly studied and advocated by Bunting.

Antoine de Heyde (1684), Clopton Havers (1692), Duhamel du Monceau (1739) and Troja (1761) must be given due credit for their careful observations concerning the gross and semiminute structure of bone.

They were also the first to conduct animal experimentation involving the question of the origin of osseous tissue.

However, the most valued early observations, were those of Virchow and Ollier (1858). Working separately on this important question, the origin of osseous tissue, Virchow developed the metaplastic theory of bone formation while Ollier supported Duhamel's theory of the periosteal formation of bone and attributed especial histogenetic importance to the osteoblastic layer of the periosteum.

Later Barth, Axhausen and others have presented many valued contributions to the subject.

BONE A LIVING TISSUE.

It must be constantly borne in mind that bone is a living tissue, subject to the same economies of metabolism as any other living tissue in the animated kingdom. It is far from being an end-product, as one might be lead to believe after driving metallic nails, screws and bolts into this living tissue. It undergoes both progressive and retrogressive metabolism throughout its life. Old bone is continuously undergoing absorption, and new bone deposited in its place. It is the storehouse of calcium, ever ready to supply it when in demand to maintain the metabolic equilibrium of the human economy, just as fat is stored up by the panniculus adiposus, and as the liver stores up glycogen.

All living tissues are subjected to internal metabolic changes associated with constant absorption, renewal and repair from the time of their inception as an entity until complete cessation of their activities. These internal cellular activities appear comparatively simple, when applied to soft, cellular tissue derived directly from cellular entities of its peculiar type, but when contrasted with tissue of a hard, compact texture, the regeneration of which is dependent upon proliferation of an undifferentiated mother cell, the complexity of the process, without careful consideration, is almost unsurmountable. The close, compact, hard texture of the calcified matrix, simply offers added resistance to its permeability, delaying the metabolic processes of interchange between its individual cellular cytoplasmic masses, only being a matter of time, all processes proceeding eventually as in any other living tissue. Metallic nails, wire, bolts and plates used in the treatment of fractures, etc., produces localized necrosis from pressure and later absorption, until the equalization of pressure by absorption becomes compatible with the vitality of the adjacent living tissue. The resultant absorption from very limited pressure applied continuously over a small area is constantly being observed in the progressive erosion of the ribs and sternum under the pressure of an aneurysm of the aorta.

Osseous tissue is very susceptible to perverted metabolic processes as is seen in the pathological changes produced as a result of rickets, syphilis, tuberculosis and osteomalacia.

COMPLEXITY OF BONY STRUCTURE.

One of the most singular difficulties in the experimental researches in which bone is under consideration, is its complex histological structure. Many highly differentiated tissues are present in the structure of bone, *i. e.*, the Haversian system of canals contain vascular endothelium, fibroblasts, developing osteoblasts in all stages of maturation, lymph spaces and all the elements of circulating blood, its matrix, consisting of osseomucin and fibrils from the cells, its highly specialized ground substance capable of supersaturation with the earthy salts. In any experiment in which bone is the centre of attention, it is of paramount importance to keep in mind the constant presence of the osteoblast, which cannot be differentiated morphologically from the ordinary embryonic cell of fibrous tissue but which is endowed with the specific property of secreting osseomucin and destined to become, after due course of differentiation, the mature bone cell, surrounded by its calcified stroma.

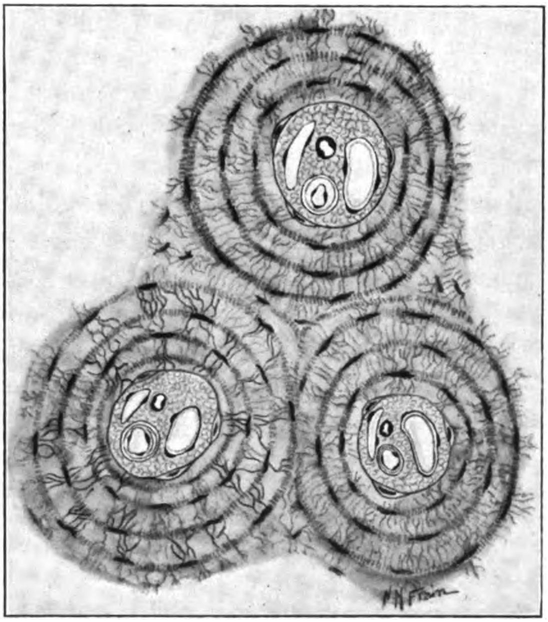

FIG. 6.—Cross-section showing the contents of the Haversian canals, artery, vein, lymph vessel, osteoblasts, and loose connective tissue.

By virtue of its inherent power, it is the sovereign of calcium deposition within the area over which it predominates, being also capable of producing its dispersion. In the absence of any data up to the present writing, the mature bone cell is an end-product, incapable of regenerating itself. The existence of the intercellular stroma is absolutely dependent upon the activity of the mature bone cell, for in the event of its death the calcareous matrix, over which its supreme jurisdiction reigns, continues to remain "inherently immutable" demanding time, foreign-body giant cells and occasionally mechanical interference for its removal. While it is very probable that the stimulation of mitosis in the mature bone cell can be accomplished by incubating *in vitro* on special lymph media, nevertheless this does not necessarily indicate the direct reproduction of new bone. Mitosis is not always inherently synonymous with differentiated tissue growth.

The many modes of development of osseous tissue only serve to increase the perplexity of the ultimate structure; no tissue in the human body has as many different methods of developing into a structural entity as bone.

CELLULAR DYNAMICS.

The transplant, as a unit for future growth, is a multicellular mass consisting of the entire quota of differentiated and undifferentiated cells present in the parent tissue. This multicellular mass must not be regarded as a mass of separate and distinct individual cellular units, but rather as constituting an interdepending aggregate of minute units. Clinically, from the standpoint of mechanical adaptability and efficiency the mass is the unit; however, for an inquiry into the ultimate fate of the multicellular mass, subsequent to transplantation, the cell and not the mass is the unit for consideration. The mass before its removal is subject to the normal physiological metabolism of the parent tissue, functionating and storing up energy for repair and growth. There still remain many mysteries concerning the physiological mechanism of that circumscribed piece of bone which, with a few strokes against the chisel and an inoffensive buzzing of the saw, will shortly constitute the entity over which many words have been written and many more must be written.

Simply separating this circumscribed living cellular mass of tissue from its well-regulated supply of assimilative material—the constituents of the blood and lymph—does not mean death to its individual cells. Somatic or organic influence is not essential to continuous cellular existence, within certain limits, and under proper chemicophysiological environment it is possible for a certain cellular mass to retain its inherent vitality for a variable length of time subsequent to its enforced separation from its original somatic environment. The continued existence of the individual units depends upon their individual capacities for storing up reserve energy. Likewise, the future life of the transplant depends upon the same capacity. All transplanted tissues—bone included —are influenced by these few physiological factors.

Successful transplantation of bone is dependent upon the continuance of the cellular life of its individual elements and necessitates their growth and regeneration. Growth and regeneration are so intimately associated with complex cellular phenomena, that it is essential for the adequate comprehension of the physiological mechanism involved in the transplantation of tissues to give a brief résumé of applied cellular dynamics.

The living cellular elements of the proposed osteoplastid, while under the influence of the metabolism of the donor is subjected to different types of activities, *i. e.*, katabiotic (functionating) and bioplastic (growing) activity, respectively, discharge of kinetic energy into potential energy, *e. g.*, storing up energy in the construction of the complex bioplasm of the cell substance—in growth. Katabiotic activities are the responses to external stimuli, either "directly or through the intermediation of the nervous system." Since the main purpose of the transplant during the early part of its existence is supplied by its compact, hard texture in providing absolute immobilization and maintaining accurate coaptation, we can dismiss further discussion of the katabiotic activity at this time since the performance of function is *nil.* The more highly differentiated a cell becomes for the performance of specialized function the less are its vegetative activities.

The continued activity of the transplanted mass depends upon the amount of potential energy that it has stored up previously to its removal from the donor. The more highly differentiated cells will have stored up a minimum of potential energy, *i. e.*, the functional demands placed upon the bone cell is so great and hence its bioplastic activity so limited that even in the most favorable environment, it (bone cell) could not be expected to regenerate sufficiently to maintain the unity of the graft. Therefore since the vegetative potentiality of the bone cell is *nil* the regeneration of bone must come from a more embryonic cell. "The more we study the differentiated tissues of the body the more it is brought home to us that the fully developed and differentiated cell, as such, exhibits little active multiplication, and that to a very large extent under normal conditions the removal of the cell worn out by use is brought about by the presence and reproductive activity of "mother cells," that is, of cells present in the tissues in a relatively undifferentiated form, or, as we are accustomed to term it, of embryonic type." (Adami.) The embryonic type of bone cell is the osteoblast which is omnipresent in true osseous tissue. They are present in great numbers in the compact periosseous layer, in the Haversian system, the marrow and endosteal layer. Growth is a specific function of these osteoblasts and this property reaches its maximum; the only function performed by the osteoblast is the formation of mature bone cells and this is vegetative in character—performance of function is at a minimum. Assimilation and vegetative activity with very slight, if any, functional demands are the distinctive features of their existence. The length of time a graft can exist before a new supply of pabulum is furnished, is dependent upon the reserved potential energy stored up by its component cytoplasmic masses. This reserve capacity of the cytoplasmic units is exceedingly variable, but this margin of safety of reserve energy means either life or death to the transplanted cells. The reëstablishment of the blood supply may be accomplished in a few hours or not for many days, however, as the supply of pabulum gradually increases so as to be compatible with the demands of the graft, the cells having used up their reserved energy for self-preservation, are in active demand for assimilative material; these demands being supplied and an excess of pabulum being present the cells are stimulated to growth. Less reserve capacity is required by the cells, for their future welfare, in the periphery of the graft than those encased in its centre surrounded by an impermeable calcium matrix. The cells in the periphery of the graft will be bathed in the serum of the host more readily than those situated in the centre, therefore the bone cells situated any distance from the the new supply of pabulum will become necrotic along with its corresponding calcium stroma. The necrotic ground substance must undergo dissolution before new bone can be laid down. · It is very probable that the dissolved calcium salts are reprecipitated by the rapidly maturing osteoblasts.

The osteoplastid is a multicellular entity, consisting of many cellular constituents, the fundamental cell material of each component being formed of complete biophores, which have the inherent property of reproducing themselves, and thus stimulating growth. The limitation of growth of each unit mass of biophoric material in the bone cell is dependent upon three factors: (1) the ratio of the surface contact of the unit mass of biophoric material to the intermediate substance (the cytoplasm); (2) the relation of the cytoplasmic mass to the surrounding assimilative material (plasma of the host) and (3) the distance the majority of the cells, which have sufficient reserve force to insure their future maintenance, are situated from the periphery of the graft. The relation between the maximum efficiency of the cell and its surface contact is constant. As soon as this constant coefficient is exceeded—*e. g.*, an increase in the surface contact of the biophoric material in the cytoplasmic substance—one factor is immediately diminished by nuclear division and coincident cytoplasmic division, thereby maintaining a coefficient compatible with the optimum cellular efficiency. Each cell of the transplant is existing under different environment, so that the coefficient of efficiency varies for each cell according to its location in respect to the periphery of the graft. The surface contact of biophoric material situated in the centre of the graft must necessarilly be much greater than if situated at the periphery, *e. g.*, more remote from the maximum supply of pabulum. If the reserve capacity of the transplanted cell is not sufficient to be compatible with the enforced optimum coefficient the cell dies. Likewise, indirectly the calcium stroma is dependent upon these three factors. Variation in any one of these three factors, within certain limits compatible with the life of the cell, will produce variations in the ultimate product and, if continued for any length of time, will be associated with alteration in the cytoplasm, *i. e.*, gross changes in the biophoric material and corresponding histological and physiological modifications of the entire cell.

HEALING OF SIMPLE FRACTURES.

In the practical application of the medullary transplant, there is a dual process taking place which adds to the complexity of the process of healing in the osteoplastid. The ends of the fractured fragments will eventually unite by a more or less complex process, while at the same time absorption, repair and regeneration are taking place in the transplant. The main features of the method by which union occurs between the ends of the fragments, without the interposition of the graft, will be given.

The defect which exists between the ends of the fractured bone bridges over with callus. This callus, while continuous throughout its extent, can be divided for explanatory purposes into three portions, *i. e.*, periosteal, medullary, and intermediary. The process from the beginning, immediately after the solution in the continuity of the osseous tissue to completion of the ultimate consolidation passes through three distinct stages of metamorphosis, although not distinctly separable since one stage may advance more rapidly in some portions of the callus, while another stage may be delayed. All portions of the ultimate calcified bridge must pass through these stages, *i. e.*, primarily, a formation of fibrous callus; secondly, its ossification which at first is only a provisional process, but later is completely substituted by a permanent compact structure; and, thirdly, reduction and molding.

The periosteal callus is formed very early and is derived from the periosseous layer of osteogenetic cells. It is usually very extensive, much in excess of functional demand and its size is dependent upon proper coaptation and efficient immobilization. Its formation begins with the first fibrinization of the blood-clot and is continuous until the fourteenth to seventeenth day.

The medullary plug or callus (which is not formed when the medullary transplant is employed) forms synchronously with the periosteal callus and is derived from the proliferation of the endosteal osteogenetic cells and also from certain cellular elements of the marrow substance. It consists of a highly vascular, fibrous connective tissue, extending into the medullary cavity of both the proximal and distal fragments a varying distance. This portion of the process is completed by the tenth to fourteenth day.

The formation of both the periosteal and medullary callus is dependent upon the extent of comminution (more spicules of bone to undergo necrosis and absorption).

Immediately following the injury a limited amount of exudation of blood and lymph takes place, which ordinarily is held within the unbroken periosteal tube of fibrous tissue. Necrotic cells and fibrils, together with blood corpuscles are eventually dissolved and absorbed. Free fat, which in very limited comminution is much more than would be ordinarily expected, "is taken up by the endothelial leukocytes." (Mallory.) The extravasated lymph and blood gradually undergoes organization with the formation of a very vascular, fibrous connective tissue. The compact bone immediately adjacent to the line of fracture becomes decidedly more porous and there is practically a condition of rarefying osteitis. (Woodhead.)

The intermediary callus is the last to form and is derived from the periosteal and medullary callus by an ingrowth from them which in time unites between the ends of the bone. No portion of this callus is ever derived from the fractured ends of the bone. The ossification of this portion of the callus is very slowly accomplished.

With the completion of the formation of a continuous fibrous callus the second stage of repair begins. Extending usually at right angles to the old compact bone are seen fine trabeculæ of osteoid material forming in the recently organized, highly vascular fibrous tissue. Later the osteoid trabeculæ become thicker by surface deposition, gradually filling in the entire space with closely packed trabeculæ. Into this material lime salts are deposited. Ossification of the medullary callus is brought about by a direct metaplasia of fibrous tissue without intermediary cartilaginous formation. Ossification is always farther advanced near the adjacent supply of osteogenetic cells.

Ossification of the periosteal callus may be direct without cartilage formation or indirectly by the metaplasia of cartilage into bone. The method of ossification is dependent upon the size of the organized mass of exudate, which in turn is dependent upon the proper coaptation and efficient immobilization. A large callus requires the intervention of the cartilaginous stage for its metamorphosis.

Ossified callus consists of interlacing trabeculæ of bony plates separated by a very vascular connective tissue. The entire callus is very spongy and lacks stability. It is known as the provisional callus. The provisional callus gradually undergoes absorption and replacement by compact bone. However, the entire provisional callus is not always replaced by compact bone. The extent of permanent replacement varies with the type of fracture and also with its reduction. The medullary portion of the provisional callus is not replaced by compact bone where perfect alignment has been maintained, but gradually undergoes absorption. In those cases of permanent callus formation, the entire provisional callus is most always replaced, while subsequent absorption of the medullary portion, with the reëstablishment of the medullary canal may never occur.

The permanent ossification of the intermediary portion of the callus is the last to take place. This probably depends upon the atrophy of the ends of the fragments. No permanent process is established in the presence of the degeneration products of necrotic tissue. Not until the atrophied ends are regenerated will the permanent process be inaugurated. The permanent ossification of the intermediary callus may not be accomplished for months. (Approximately seven to nine months in the tibia of a dog and if conditions are not favorable, this time is materially increased.)

The third stage in the process of repair of fractures (in this work) is based entirely upon the interpretation of röntgenograms. The medullary and periosteal portion of the callus diminish in size. The medullary portion finally undergoes complete absorption with the restoration of the continuity of the medullary cavity. The medullary callus, no doubt, undergoes atrophy from disuse. While the medullary canal is restored, its lumen at the site of the fracture is never as large in diameter as the original diameter at the same site.

Prevention of the formation of callus is materially influenced by syphilis, either active or quiescent. (Sansom, Beaulac, Coudie and many others.)

HISTOGENESIS OF OSSEOUS TISSUE.

Bone is a connective tissue, supersaturated with calcium salts and like all other connective tissues is formed primarily from a blastemal syncytium; although there may be a preosseous intermediary cartilaginous stage of development. It is never of primary formation and is always derived from mesenchyme.

The fundamental cell units from which bone is developed cannot be differentiated morphologically from ordinary immature connective-tissue cells, however, occasionally during their metamorphosis they appear epithelioid in character. These preosseous epithelioid cells are most frequently observed where lamellar deposition is taking place about preëxisting bone or calcified cartilage. The epithelioid cells were observed by Gegenbaur, in 1864, and were named osteoblasts by him. They are mostly observed collected in layers, which represents a transformation from immature connective-tissue cells, through the epithelioid stage to true bone. From the lower layers of these cells, certain cells are seen to branch, anastomose and form an osteogenetic syncytium which eventually becomes true bone.

True bone, in the human embryo, is mostly laid down in connection with a transitory cartilaginous skeleton which is later replaced. The replacement is initiated in centres of ossification, the location of which may either appear in the cartilage, in which case it is known as endochondral ossification, or they may appear beneath the perichondrium, and is then known as subperiosteal ossification. The majority of the flat bones of the face and skull are formed directly in fibrous connective tissue and is called intramembranous ossification.

A brief description of the process of ossification together with the particular features characteristic of intramembranous, subperiosteal and endochondral ossification will be given.

Although it is convenient to describe three distinct types of bone formation, one differs but little from the other. In both intramembranous and subperiosteal ossification, bone is developed in embryonic connective tissue through a process of metamorphosis of this tissue into osteogenetic tissue which is later converted into bone. Intracartilaginous bone differs from the other two types only in that cartilage is formed within embryonic connective tissue in the general conformation of the future bone. It must be borne in mind that bone is developed in this cartilage and not from it, bone being a product of osteogenetic tissue which is derived from mesenchymatous tissue pushed into the cartilage by the periosteal bud.

INTRAMEMBRANOUS OSSIFICATION.—The regions of the embryo in which this type of ossification develops consists of embryonic connective tissue. In certain minute areas, known as calcification centres, the connective-tissue fibrils become impregnated with calcium salts. In each of these areas the cells increase in numbers, many new bloodvessels are observed and the cells are seen arranging themselves in single layers along the calcified fibrils, and become differentiated into mature osteoblasts. Under their influence calcium salts are deposited between the cells and the calcification centres become the centres of ossification. Ossification begins at a centre and radiates peripherally.

During the early period of ossification about a centre all stages of bone formation may be observed from fully matured bone to an undifferentiated embryonic connective-tissue syncytium. Layer upon layer of calcium salts is laid down by the osteoblasts and some of these cells become enclosed by the newly deposited calcium matrix and form bone cells. In this manner only trabeculæ of bone are formed, completely surrounded by spaces containing osteogenetic tissue and is known as spongy bone. After the bone has ceased to develop peripherally the trabeculæ become thicker and gradually come together forming compact bone. Some of the spaces between the trabeculæ at an early stage of development become converted into canals containing bloodvessels and primitive marrow.

SUBPERIOSTEAL OSSIFICATION.—From the deeper layers of the periosseous osteogenetic cells, bone is formed as a coarse interlacing structure, the meshes of which contain vascular embryonic marrow. Dense subperiosteal lamellæ of bone are formed, in human bone, between the first (Kölliker) and fourth (Schwalbe) years after birth. This method of ossification is the only process of substitution of bone for cartilaginous tissue in certain bone (as in ribs). It may develop coincidently with endochondral ossification (diaphyses of long bones).

ENDOCHONDRAL OSSIFICATION.—The earliest changes in the process of endochondral ossification are an increase in the size and the number of the cartilage cells through karyokinesis, relatively reducing the matrix in amount, simultaneously with the deposition of calcium salts in the homogeneous ground substance of the cartilage, making it opaque. Many cartilage cells lie in each cartilage lacunæ. The lacunæ eventually become much enlarged and their contents become shrunken, forming comparatively large spaces, known as the primordial or primary marrow cavity. Areas in which these changes are taking place are known as ossification centres.

The changes in the structure of the cartilage are accompanied by bone formation in the periosseous osteogenetic layer (subperiosteal ossification). Thus at the border of the cartilage is developed a layer of osseous tissue.

Into the primary medullary spaces, previously formed in the cartilaginous matrix, processes or buds, called periosteal buds, from the periosseous osteogenetic layer of cells are seen to develop, penetrating the calcified matrix, allowing the cells of the cartilage to become free. These buds from the deep cellular layers of the perichondrium are endowed with destructive power which produces dissolution of the cartilaginous matrix and with constructive properties which produce bone formation. These spaces contain the primitive marrow which is vascular, and contains undifferentiated embryonic syncytium, osteoblasts and osteoclasts (which appear early, while fat and marrow cells come later). The contents of the spaces are derived from the processes of the perichondrium and the remains of the cartilage cells. On the surface of the primary marrow spaces the osteoblasts deposits new bone, this constitutes spongy endochondral bone. Spongy endochondral bone is not permanent and is later absorbed during the formation of the permanent marrow cavity. The process of ossification is continuous and cartilage remote from the ossification centre gives the least evidence of alteration from the type of primitive hyaline cartilage, while near the centre of ossification is seen successive changes of cellular proliferation, cellular expansion and calcification of the ground substance.

The dissolution of the spongy endochondral bone is accomplished by the action of the osteoclasts—large, multinucleated giant cells, the origin of which is unknown. The Haversian spaces are formed during the process of dissolution and later bone is deposited layer upon layer by the osteoblasts until these spaces become narrow channels—the Haversian canals. The layers of bone are the Haversian lamellæ.

The ultimate fate of the cartilage cells during the dissolution of the calcified matrix is still in dispute. Kölliker, Sharpey and Lovén conclude that the cartilage cells are destroyed, while Müller, Ranvier and Retterer believe that the cartilage cells become converted into osteogenetic tissue, each cartilage cell giving rise to several small cells and to reticular tissue.

Disse (1909) describes the osteogenetic tissue as arising from the cell protoplasm. Each osteoblast becomes divided into two parts, a perinuclear granular portion and a peripheral, usually basilar, hyaline portion. The hyaline substance derived from the osteoblasts fuses to form a mass in which fibrils differentiate after the hyaline substance is separated from the perinuclear protoplasm.

"The ground substance of bone is intercellular and not intracellular, since the osteoblasts secrete the ground substance as Kölliker and others have demonstrated."

THE METAPLASTIC THEORY OF BONE FORMATION.

HETEROTOPIC FORMATION OF TRUE BONE.—In the discussion of the regeneration of bone, it may not be considered a digression to inquire into the origin and mode of formation of true osseous tissue in unnatural locations in the human body, since in some instances the new tissue is remote from any of the histogenetic components of the fully developed tissue. True bone is occasionally found in the walls of bloodvessels, in the choroid coat of the eye, in scar tissue after operative procedures and in the ossification of laryngeal and tracheal cartilage in advancing age.

For many years the heterotopic formation of true bone was considered a rare incidence. But, since the work of Barth (1895), Pollack (1901), Sacerdotti and Frattin (1902), Poscharissky (1905), Bunting (1906), and Brueger and Oppenheim (1908) the formation of true bone, even with its associated cellular marrow (red) is not an uncommon occurrence. W. Harvey (1907) of Toronto was able to produce true bone in the aorta of rabbits by the application of irritants to the vessel walls. In from two to six months, after the application of a 3 per cent. solution of silver nitrate or a 2 per cent. solution of copper sulphate to the outer coat of the vessel wall of the aorta, Harvey was able to demonstrate the formation of bone with its Haversian canals, with bone-marrow or bone alone, or the development of osteoid tissue in areas of calcification. A very important question naturally arises, as to the origin and mode of development of bone in these unnatural situations.

Several theories have been advanced to explain the origin of heterotopic bone formation. Some have endeavored to apply Cohnheim's theory of "cell rests" —*i. e.*, inclusion of aberrant tissue or mother cells—to explain the presence of the histogenetic fundaments for the future development of true bone in these unexpected situations, and that by some unknown force these misplaced embryonic cells take on active vegetative development. While the presence of cell rests must be admitted and that such inclusions are frequently present is true, notwithstanding it cannot be admitted that aberrant tissue rests of the histogenetic fundaments of osseous tissue are constantly present in the intima of bloodvessels or in the choroid coat of the eye. Again, the incidence points to such a preponderance of frequent occurrence of the process in advanced atheroma of arterial walls. Certainly, there is no basis for such a hypothesis.

Ribbert details to the osteoblasts the specific function of the production of bone and its transportation to the proper situation by the blood stream. This theory necessitates the assumption that the osteoblasts are wandering cells, derived from bone and marrow in other locations. While this possibility must logically be admitted, nevertheless it is greatly improbable and practically free from derogatory experimental proof. It must be admitted that embryologically bone is derived from connective tissue by a process of physiological metaplasia.

The most plausible theory of heterotopic bone formation is the metaplastic theory. The assumption is that bone production is the result of alteration in the function and nutrition of certain of the connective-tissue elements, *i. e.*, metaplasia or the production of highly differentiated tissues from cells which are primarily destined to produce tissues of a lower order of specialization.

To return to the first appearance of true bone in the embryo, it is readily seen that the highly differentiated osseous tissue is developed by a process of physiological metaplasia from the primary mesoblastic tissue—mesenchyme, accompanied by a deposition of calcium salts. We must not forget that metaplasia is a constant process in the living body, occurring both as a physiological and pathological process, as is seen in the conversion of cartilage into bone (Adami) and ordinary connective tissue into fat cells.

Bone has always formed where young connective tissue is adjacent to calcium deposits and the metaplastic process is evidently a result of the chemical stimulus of the calcium salts. Pollack found true bone formation adjacent to the calcium deposits in 43 out of 47 cases in which the process was studied. Bone cells, marrow cells and connective-tissue cells are all developed from the undifferentiated mesoblastic cells, but in "adult life they seemed to have diverged widely in nature and function." The specialized differentiation of a fibroblast into an osteoblast is a short step and is dependent upon the nature of the intercellular substance deposited.

There are two views concerning the formation of bone in heterotopic tissues, *i. e.*, "(*a*) that there is a direct metaplasia of connective tissue into bone after the manner of callus formation and (*b*) that the calcific material is eroded with the formation of vascularized spaces containing tissue cells, some of which take on the function of the osteoblasts and lay down bone, some of the osteoblasts becoming included and forming the bone cells." (Bunting.) Paul describes the process as consisting of three stages as follows: (*a*) calcareous degeneration; (*b*) irritation about these areas of degeneration from fracture or other injury leading to inflammatory proliferation; (*c*) ossification in this young proliferating tissue. "It seems clear, then, that one has here a metaplasia of connective-tissue cells into osteoblasts, for in the vessels and heart valves there can be no possibility of periosteal or perichondrial sprouts playing a part, except in pulmonary foci. As to the stimulus which leads to this metaplasia, there seems to be a uniformity of opinion, as might be expected from the similarity of pictures presented by the different cases." (Bunting.)

INDIRECT REGENERATION OF MATURE BONE CELLS.

The process by which tissue elements are renewed after destruction is known as the regeneration of tissue.

The reproduction of highly specialized tissue is accomplished by the regeneration of its cellular elements, usually mother cells. Highly differentiated tissues, as a rule, are developed from so-called mother cells, while the less differentiated tissues are regenerated direct. The ultimate tissue may be regenerated either (*a*) through a process of direct regeneration (*e. g.*, epithelial cells from epithelial cells), or (*b*) by the indirect regeneration from mother cells (*e. g.*, regeneration of erythrocytes from the mononuclears, mother cells of the marrow substance, etc.). The reproduction of mature bone cells is an example of the latter type of regeneration.

The reproduction of new bone from bone is a very complex process and includes the dissolution of the old ground substance and the synthesis of new bone. New osseous tissue cannot be regenerated from matured bone cells, since a bone cell is an end-product and cannot regenerate itself, but must depend upon the undifferentiated osteal fibroblast (mother cell) for its constant reproduction and the ultimate formation of true osseous tissue. Regeneration of bone cannot be accomplished by the reproduction of bone cells by mitosis. The process of indirect regeneration of bone has been the stumbling block of many researches in this field of experimentation. There is no available data, at the present writing, that a bone cell may undergo division and multiplication by mitosis. Moreover, mitosis is not always synonymous with tissue growth.

Should a bone cell die, through a deficiency of its inherent internal assimilation or a deficient supply of pabulum as may happen in a transplant, the surrounding calcareous matrix over which the bone cell predominates, does not undergo constant replacement and absorption, as any living tissue must, but remains unchangeable only to be removed in due course of time by the endothelial leukocytes, osteoclasts, etc. Therefore, any new bone that is deposited, as in the case of a transplant, must be derived from the indirect regeneration of the osteal fibroblasts either of the transplant or of the host. This does not mean that all transplanted bone dies and that all new bone is laid down by the indirect regeneration of the osteal fibroblasts. Some bone cells are capable of retaining their inherent vitality and internal assimilation and reign supreme over their stipulated area of calcified matrix. However, it must be admitted, whether by analogy or by direct proof, that the entire quota of constituents of any transplant will not live—cannot live—while other constituents more favorably situated will be bathed with the necessary pabulum compatible with the retention of its inherent vitality.

SPECIFICITY OF THE OSTEOBLAST.

A definitely specialized function has been assigned to the osteoblasts by Ribbert. On the basis of such a theory, heterotopic bone can only be formed by the activity of these highly differentiated cells and necessitates the assumption that these specialized cells are present in the blood stream, which for some unknown reason are deposited, probably following trauma, with the formation of bone. "This possibility must be admitted, but is it the greater probability? We think not." (Adami). The osteoblast, if carried by the blood stream, cannot be identified as such, with our present hematological technic. As to its specificity, it is sufficient for the present, from animal experimentations, to say that its specificity is very doubtful. During the embryonic formation of bone the ultimate osseous tissue is derived by a process of physiological metaplasia of the mesoblastic cells into specialized bone-forming cells and cannot be differentiated from the ordinary connective-tissue fibroblasts. The specific histogenetic properties of a differentiated fibroblast are due to combined action of its environment, its relation to the bloodvessels and the functional demands placed upon it. The theory of the metaplastic formation of bone in the walls of the bloodvessels has much in its favor.

GROWTH OF BONE.

To obtain successful results in some cases of transplantation of bone, it will be necessary to carefully consider the process or processes by which osseous tissue increases in length, width, and thickness.

Primarily the growth of skeletal tissue is dependent upon the internal secretion of both the pituitary and thyroid glands as is seen in cretinism, gigantism, and acromegalia. The lamellar deposition seen in osteitis deformans is probably due to a disturbance in the secretion of the pituitary gland. McCord has shown very conclusively, by feeding pituitary gland substance to young, developing animals, that in some manner it exerts an appreciable influence upon the formation of bony structure. Feeding pituitary extract to fracture cases does not influence the time of permanent callus formation nor complete union of the fractured fragments as has been demonstrated experimentally.

Bone increases in size both peripherally and longitudinally. Some observers have attributed an interstitial growth to bone. These three methods of growth will be discussed separately, although the increase in size of the bony structure is due to the synchronous development of each type of bone formation.

The longitudinal growth of bone is a very definite process and is initiated in a tissue which is inherently capable of the accumulation of the maximum amount of potential or bioplastic energy. This specially endowed tissue is very favorably situated at the extremity of the bones and is free from undue pressure. Bone formation takes place at the metaphysis, *i. e.*, diaphysial side of the epiphysial cartilage. In this location, the osteoblasts receive an abundance of pabulum for the continuance of the accumulation of bioplastic energy and also sufficient space for their proliferation, free from unnecessary crowding of the ultimate individual constituents. The growth of bone in this particular locality is dependant upon the ossifying cartilage, which is only a transitory tissue subject to the stimulation of the internal secretions with the ultimate formation of new bone. Destruction of the cartilage at the epiphysial line with the complete elimination of this particular structure will be followed by retardation or complete cessation of development of osseous tissue. While the longitudinal growth of bone is normally limited to the metaphysis, nevertheless should the same condition exist in any portion of the diaphysis, the osteoblasts in this area would be stimulated to increased vegetative activity with the concomitant formation of the specialized ground substance. These conditions prevail in the diaphysis when an entire section of the circumference of the shaft is removed. The gap will eventually be filled in by the proliferation of the osteoblasts, both from the ends of the bone and from the remnants of the periosseous osteogenetic layer of the bone. Bone deposited under these conditions will not be governed by any inherent hereditary tendencies as to its ultimate conformation and will be more or less irregularly deposited, depending upon the associated trauma, etc. Any diminution in the pressure upon the metaphysis is associated with renewed activity of the osteoblasts and the formation of bone pushing the entire shaft toward the defect.

Bone is increased peripherally by the activity of the periosseous osteogenetic layer of cells, producing the deposition of new circumferential lamellæ. However, while the external diameter of the bone may be increased in size, there is very little increase in the bulk of the osseous substance, since any increase in the periphery of the bone is accompanied by a corresponding osteoclasia along the medullary canal. Only an increased functional demand will produce an increase in the quantity of osseous tissue. This view is the one generally accepted during the period of development, but is contested during adult life.

The interstitial growth of bone does not refer to the deposition of new bone in the interstices of the osseous tissue nor to growth, in the sense that two given points will eventually become separated a greater distance apart from the deposition of new osseous tissue between them. Bone being a living tissue requires all the accompanying changes associated with internal cellular assimilation, *i. e.*, renewal, absorption and repair which are constantly associated processes in the normal metabolic economy.

BRIEF RÉSUMÉ OF THE LITERATURE.

A brief résumé of the literature will be given, an attempt being made to limit the résumé of each investigator's researches to the statements and conclusions, specifically referring to the regeneration of bone *per se*. No attempt will be made to discuss pro or con the conclusions, but rather to allow each individual, unbiased, to formulate his own deductions.

Axhausen (1907–1909): "The chief source of new bone which replaces the necrotic bone of the transplant, is the periosteum, next in order comes the marrow and endosteum and third, only in case of implantation into bone defects, the osteogenetic tissues of the implantation site."

Tomita (1908) concludes that the new growth of bone comes from the inner layer of the periosteum and from the marrow cells. The cells of the bone itself has no power to form new bone.

Wieder (1908): "In the regeneration of bone all the various elements, viz., periosteum, cortex, endosteum and marrow assist in the process. Cortical bone-forming activity does not manifest itself until after considerable absorption of the cortex has occurred so that it may be due to the liberation of bone cells which take on new activity and again precipitate the liberated calcium salts in new situations; or it may be due to the opportunity for the ingrowth of endosteum into the widened spaces. The deeper layer of the periosteum, the endosteum, the tissues lining the Haversian canals and the bone cells are probably all related or identical tissues exhibiting different activities because existing under different physical conditions."

Baschkirzew and Petrow (1912): "There remains nothing else possible than to accept the view that the chief source of the regeneration of bone, transplanted into soft parts, lies in the primary layer of granulation tissue which surrounds the transplant. Bone in different degrees of necrosis seems to exert a specific irritation upon the connective tissue. Bone freed from periosteum and transplanted into soft parts proves itself capable of regeneration; periosteum is as little necessary as the marrow."

Cotton and Loder (1913): "The essential picture is summarized as follows: Disappearance of the bone cells in the trabeculæ of the transplant and also to some extent in the host. The graft is covered by a layer of endosteal new bone which unites with endosteal new bone of the host. New bone is formed by the activity of the endosteoblasts in all portions of the graft, centre, and periphery."

Lewis (1914): "Cortical bone free from its periosteum, endosteum and marrow will retain its vitality and proliferative power when subdivided into small fragments and replaced into the tissues. Contact with living bone is unnecessary for the growth of the transplant. Larger pieces of bone may be transplanted and remain alive—not being merely grown into by the bone in which they come into contact. Bone may unite after a fracture, or a space fill in after resection without the aid of any periosteal or bony bridge. Contradictory results of careful observers can be explained by the variation in one factor, namely, the amount of blood supply which the transplanted bone obtains."

Bancroft (1914), in discussing the process of repair of bone following trauma, states that "One is impressed with the idea that the calcium salts have been laid down upon ordinary granulation tissue in the perivascular spaces; that is, in the area farthest away from the bloodvessels. This is early formation of new bone."

Mayer and Wehner (1914) state that "Under favoring conditions many bone cells of the transplant can maintain their vitality until the transplant has become vascularized. The cells of the Haversian canals, particularly of young bone, possess osteogenetic power provided their vitality is maintained. A greater part of the transplant necroses and that these necrotic areas are gradually replaced by new bone derived from the specific osteogenetic cells of the periosteum, endosteum and Haversian canals. In bone transplants the bone cells showed no new formation of bone.

A part of the transplanted bone dies, another part lives until the transplant is vascularized. The dead bone is partly dissolved by the young bone cells which form new bone at the same time, which is gradually substituted for the old bone and penetrates into the empty bone cavities."

Gallie (1914): "Death of the bone graft in the first week. Revascularization of the graft by the second week. "In bone grafts as well as in living bone, bone absorption and bone building are properties of living bone cells. By the end of the third week the graft is completely covered by new bone."

McWilliams (1914): "Living bone grafts have life inherent in themselves and are capable of permanent growth even when transplanted into soft parts."

Phemister (1914): "Osteogenesis in bone repair occurs from the inner layer of the periosteum, from the endosteum, and to a much less extent from the bone cells and fibrous content of the Haversian canals. The great mass of bone cells being away from the surface and surrounded by an extensive and difficultly permeable calcified matrix gradually undergo necrosis and absorption. A few (bone cells) about the periphery and lining the larger vascular spaces as well as the fibrous elements of the latter may survive and proliferate. A fracture through a transplant unites by callus formed from the surviving cells of the transplant in the vicinity of the fracture."

Macewen (1912): "The vegetative capacity of the bone cell is at least as great as that of the epithelial cells. Diaphysial bone grafts live and actively proliferate in their new surroundings. Diaphysial bone is produced by the proliferation of the osteoblasts derived from the preëxisting osseous tissue. As long as the bone cell remains embryonic it exhibits the power of proliferation; but when it reaches maturity, it assumes the fixed tissue type and becomes stationary. This period is coincident with the calcareous deposition and with it the cessation of active regeneration, though its proliferating potentiality still remains. The regeneration of bone is proportionately in inverse ratio to the size of the graft. "The vegetative capacity of the bone cell is as great as that of the epithelial cell, and if one grants not only the vitality of the transplanted epithelium, but also its power of extensive proliferation, then judging by analogy, the bone cells ought to show equal capability of living and growing when transplanted."

That practically all the bone cells of the transplant necrose is supported by Barth, Bonomme, Marchand, Saltykow, Axhausen, Frangenheim, Baschkirzew and Petrow, while the theory that the graft retains its vitality and proliferates is supported by Macewen and McWilliams. No doubt the process involved is as complicated as the structure is complex and no one theory will explain the changes in detail.

METHODS OF EXPERIMENTATION.

All the deductions and the conclusions, relative to the problems concerning the regeneration of bone in this section, are based upon the histopathological changes produced at varying periods of time after the transplantation. It was endeavored to confine all experimentation entirely to the practical application of transplantation, *i. e.*, mainly medullary transplantation, either employing the cortex of the crest of the tibia or else transplanting a section of the fibula complete, excluding any macroscopic evidence of any periosteal remnants; inlay transplantation employing an osteoplastid consisting of all the elements of cortical bone, periosteum, endosteum and compact osseous tissue, each of which is placed in apposition to its corresponding layer in the host. The experiments were performed upon dogs, rabbits and sheep, constantly employing either the isoplatic or homoplastic methods of transplantation. The above methods of experimentation have many points of value in their favor, nevertheless no definite method of experimentation can be entirely without criticism, since these methods involve a dual tissue reaction, *i. e.*, repair of the fracture proceed simultaneously with the regeneration and growth of the transplant. The ultimate aim has been to study the tissue reactions during an exact duplication of the practical application of the transplant in fractures, etc. Many futile attempts have been made to separate the various constituents of bone by removing the periosteum and transplanting it into soft tissues to determine its bone-forming capacity. It has been previously demonstrated that it is impossible to remove the periosseous osteogenetic layer of cells with the periosteum without at the same time removing a considerable portion of the cortex.

The osseous tissues upon removal were fixed in graded alcohol, decalcified in von Ebner's solution (HCl), embedded in paraffin and sectioned. Most sections were stained with Böhmer's hematoxylin and eosin. There was no deviation from the usual technic with the exception that all tissues were washed in a 1 per cent. solution of sodium carbonate after removal from the decalcifying solution.

FOUR FACTORS INVOLVED IN THE SUCCESSFUL TRANSPLANTATION OF BONE.

Specific chemical, physical and physiological demands are placed upon both the transplant itself and also upon the adjoining tissues of the host, whenever an osteoplastid is transplanted into bone, either to fill in a loss of substance or to act as a mechanical support to the ends of the fractured bones. These specific demands are indicated by certain, well-defined tissue changes and can be divided into four groups, namely:

1. Temporary maintenance of nutrition, not lower than the minimum compatible with the retention of complete internal assimilation of the various cellular elements of the transplant.
2. Permanent establishment of a sufficient supply of pabulum for the life of the transplant—by the reëstablishment of the circulation of the Haversian system of the transplant from the necessary constituents both of the host and the transplant.
3. Complete osseous union between the transplant and the host.
4. Eventually metamorphosis of the transplant into an osseous entity complete in its contiguity with the adjacent tissues of the host.

LAW OF FUNCTIONAL ADAPTATION.

All tissues in the living body are subjected to specific physiological and chemical demands, which either directly or indirectly produce well-defined histological modifications according to certain laws. Normal tissues are influenced materially by their immediate environment as well as by their functional requirements, as clearly described by Wilhelm Roux. Environmental and functional demands involving specific histological alterations are governed by the inherent capacity of the cell to react to external stimuli of this character. The summation of these factors and their coincident histological modifications are summarized in the statements known as the law of functional adaptation. This law may be stated as follows: The relation of the conformation, size and architectural structure of any tissue or organ is dependent upon the functional demands placed upon that tissue or organ; also any variation in either of these demands will produce histological modifications in the minute structure of a tissue sufficient to meet these variations. Transplanted tissues are not exempt from these conditions. Bone transplanted into bone, for specific physiological and mechanical reasons, exposed to varying stress and strain will be governed by the same laws as any other tissue under similar physiological demands. An osseous transplant situated in such a manner so as to supply definite physiological demands, that is, perform specific functions, will undergo specific histological modifications which will be compatible with these demands. Those bone cells retaining a sufficient reserve force to overcome the temporary enforced decrease in pabulum will become hypertrophied, subsequently taking the place of necrotic bone and finally will functionate in their new situation. That transplanted bone will hypertrophy is conceded and is well shown in those cases where a complete fibula transplant is placed between the distal and proximal ends of a resected tibia. In a remarkedly short time the fibula will increase in diameter by the circumferential deposition of new osseous lamellæ. The hypertrophy of a transplant may be either local or general and is dependent upon either the local application of increased strain upon certain portions of the graft as in the case of muscle pull or stress applied over its entire length.

In the case of the fibula transplant replacing the resected tibia, what is the important factor involved in the growth and development of the transplanted bone, which causes it to conform to the size and shape of the former tibia? While a large amount of osteoid material is probably supplied by the osteoblasts both from the shaft and the ends of the fibula, nevertheless the final deposition of new bone in the proper size and conformation is due to the deposition of bone by the inherent capacity of the osteoblasts of tibial ancestry. From the standpoint of the fibula, the resultant bone must be considered as an abnormal growth and is very improbable.

The future welfare of any transplanted tissue depends upon its usefulness, since certain functional demands are necessary for its continued existence. This is a very important biological and physiological problem, *i. e.*, economy of material and energy in the construction of any organ or part. In those transplants where there is neither physiological nor mechanical function to perform, while the cells will retain their vitality, their proliferative activity will be materially decreased. In the absence of stimulating functional demands, the transplanted tissue will in time gradually diminish in size. This has been clearly demonstrated by Lewis and Davis in transplanted tendons. Halsted has demonstrated that transplanted parathyroid tissue would undergo complete absorption unless a partial parathyropriva previously existed. Bone transplanted into the medullary cavity of a bone any distance in from the line of section will rapidly undergo absorption. This important factor, no doubt, accounts for the absorption of bone transplanted into muscle. Lack of functional demand causes atrophy and absorption.

GLASS-TUBE EXPERIMENT.

A glass tube was placed over an osseous transplant, in the manner described below, to demonstrate that the graft would increase in size, thereby proving its innate capacity to produce bone. The humerus of a rabbit was chosen, since it is by far the most adaptable to absolute immobilization. A complete section of the diaphysis, just above the condyles, was performed and after curetting away the marrow substance and endosteum, an iso-bone transplant (cortical) was snugly fitted to the medullary canal in such a manner as to allow at least 2 cm. to project beyond the end of the distal portion of the diaphysis. A glass tube which properly fitted over the diaphysis and sealed off at the opposite end was adjusted over the graft and forced upon the shaft of the sectioned diaphysis. The internal diameter of the tube about the transplant was approximately three times the diameter of the graft. The unoccupied portion of the tube immediately filled with a blood-clot, entirely surrounding the graft with nutrient plasma. Muscles and hide were sutured with silk. At the end of six weeks the rabbit was killed and the contents of the tube were examined. The free portion of the graft was twice its former size, as compared with that portion in the medullary canal. The increase in the diameter was produced by a hard substance not permeable to a needle. A slight production of osseous tissue was observed about the end of the humerus encased in the glass tube, also necrosis and absorption of the circumference of the humerus from the pressure of the tight-fitting, glass tube. The transplant immediately adjacent to its insertion into the medullary canal has not increased in diameter as the free end had done. The increase in the diameter of the free end was produced by circumferential deposition of new bone. The majority of the bone cells in the centre of the graft has disappeared, but this was associated with active

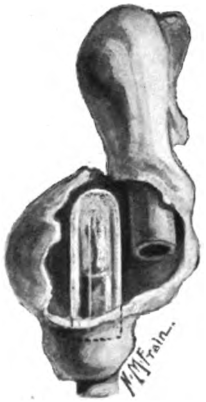

FIG. 7.—Osteoplastid inside of glass tube, enlarged considerably at the free end, six weeks after the transplantation.

proliferation of the osteoblasts in the Haversian system and particularly about the circumference of the free end of the transplant.

THE FATE OF THE BONE TRANSPLANT DURING INFECTION.

The ultimate fate of the osteoplastid, in the presence of an infection, will vary with the two following conditions: (*a*) relation of the time of infection to the transplantation; bacteriæ introduced into the transplantation bed at the same time that the operative procedure is performed will produce end-results differing from those in which the osteoplastid is inserted into a bed which had been infected some time previously; (*b*) end-results in the presence of an infection are dependent upon the component constituents of the transplanted bone, viz., the presence or absence of the periosteum will substantially modify the course of invasion by the bacteriæ and likewise, an infection of the marrow substance of a fibula transplant will also alter the course of repair. Naturally, the fate of the osteoplastid is dependent upon the virulence of the infecting organism as well as the location of the primary focus of infection.

Besides the clinical importance of the relation of the osteoplastid to infection, its permanency in the presence of an infection is of extreme logical significance in establishing the viability of the osteoplastid. The mere fact that the transplanted bone reacts to an infection is of immense importance clinically, but it also demonstrates biologically, more effectually than histological studies, the viability of the osteoplastid as a permanent osseous entity.

A few clinically successful cases have been reported following a primary infection of the osteoplastid. (Klapp, Tomita, Hashimoto, Axhausen and Lewis).

A primary infection of the transplantation bed is more disastrous to the osteoplastid than a chronically infected bed, probably because of the virulence of the infecting microörganism. Primary infection is usually associated with extensive suppuration, which causes necrosis of the graft with subsequent expulsion of the complete osteoplastid. A mild infection may be counteracted by the antitoxic properties of the serum of the host, especially if the location of the primary focus is such as to be readily permeable to the serum.

In case of a fibula transplant, the primary focus of infection may be at either end of the osteoplastid or in the transplanted marrow substance. The process of repair, which ordinarily progresses more rapidly at the ends than elsewhere, would be considerably delayed, depending upon the recognition, clinically, of a suppurative osteomyelitis and subsequently the establishment of a sufficient drainage. No doubt the systemic reaction following the transplantation of complete fibula transplants, which have been reported in the literature, have been due to an unrecognized, low-grade osteomyelitis, since in the series of cases reported in a previous section, not a single reaction of this character was observed. A properly fitting fibula transplant immediately restores the line of continuity of the bone in which it was inserted and, if infected, will seal up active microörganisms, setting free protoplasmic poisons and producing coincident necrosis of all living tissue within its sphere of toxic influence.

An infected tibia transplant (crest), if it progresses to suppuration, will eventually establish a sinus, sufficiently large to allow the necessary drainage. Infection at the line of fracture may become localized so that the transplant will become so weakened by necrosis and sloughing as to fracture through this line. Infection of a transplant with an established sinus does not effect the eventual formation of the external callus, but rather acts as a stimulus to osteogenesis and an excessive callus is laid down with the immobilization of the fragments.

Any portion of the transplant associated with an infection may undergo sequestration without effecting the viability of the remaining portion of the osteoplastid.

The ultimate fate of a transplant will vary with the component elements of the osteoplastid. The periosteum will act as a barrier to the invading bacteriæ and divert the suppurative process from invasion of the central portion of the graft. The non-osteogenetic surface of the periosteum and endosteum maintains a line of least resistance for the establishment of drainage. In the presence of a mild infection the periosteum and endosteum are much more resistant to bacterial invasion and can maintain their vitality where compact bone would undergo necrosis and absorption. Under such conditions the circulation is reëstablished more quickly, coarse, reticular new bone is deposited about the compact bone resembling very closely the involucrum observed about the sequestrum in periosteomyelitis. Associated with the deposition of the involucrum are seen evidences of absorption of the compact bone, *i. e.*, erosion of its surface, very large Haversian canals and increased porosity of the compact bone from a lack of proper balance between bone deposition and bone absorption.

OSTEOCLASIA.

The absorption of the transplant is dependent upon several factors, some of which are as follows: Improper treatment of the osteoplastid, as overheating and the deleterious action of antiseptic solutions; the ferment action of the serum against the foreign proteids, etc. The absorption of bone is a physiological process as well as a pathological process and can be studied to advantage in the alveolar process about the teeth, especially in the fetus. The process of absorption is a specific property of the large, multinucleated cells, known as the osteoclasts of Kölliker. In the region about the teeth these cells are very large and may be found in all stages of development. The origin and the fate of the cells are interesting chapters in the pathology of bone lesions.

THE OSTEOCLASTS.—*Origin.*—In the marrow substance are seen two types of giant cells: (1) megakaryocytes, which are of no interest in this connection, and (2) polykaryocytes or osteoclasts, which are endowed with the specific property of producing osteoclasis. Kölliker and Howell have attributed the origin of the osteoclasts to the fusion of the osteoblasts while Bredichin concluded that these large cells were formed by the fusion of the matured bone cells. Ranvier, Duval and Böhm oppose the theory of osteoblastic fusion and ascribe their origin to the lymphoid marrow cells while Wegener and Schaffer believe they originate in the endothelium of the capillaries. Jackson, Dantschakoff and Maximow attribute their origin to enlarged reticular cells of the bone-marrow, also stating that at first they contain only two or three nuclei and their cytoplasm is basophilic and vacuolated. The cytoplasm later becomes eosinophilic and may contain from fifty to sixty nuclei. Prentiss believes that their origin is dependent upon the stage of bone development. In the early stage of bone development the osteoclasts may arise from the reticulum of the bone-marrow, but in the later stages of bone development he is convinced that they arise from the enlargement of the osteoblasts. "They were found in all stages of transition between the osteoblastic syncytium with basophilic cytoplasm and osteoclastic masses with vacuolated, eosinophilic cytoplasm. Bone cells which have been liberated from the osseous matrix become a part of the osteoclasts. All stages in the ingestion of the bone cells by the osteoclasts were observed."

Fate of the Osteoclasts.—Kölliker and others state that after their resorptive functions are at an end these cells again become osteoblasts. Jackson thinks that the osteoclasts and bone cells are finally resorbed into a reticulum similar to that from which he believes they originated. Maximow partly agrees with Jackson, but believes that a portion of the osteoclasts undergoes degeneration and ultimately are completely destroyed. Prentiss concludes that "eventually the osteoclasts either atrophy or disappear or are resolved into the reticulum of the bone-marrow. It is not probable that they again form bone matrix."

Osteoclastic Resorption of the Osseous Matrix.—Kölliker and Jackson believe that the cells actively resorb the matrix. Bredichin thinks that the osteoclasts resorb the bone matrix and ingest the bone cells. Prentiss states that "There is no evidence to show how the bone is resorbed but it is probable that it is decalcified and digested by the action of an acid and a ferment. The fact that the osteoclasts are in intimate contact with the surface of the bone which is being resorbed points to them as active agents in the process. As the area of bone resorption of an osteoclast spreads the surrounding osteoblasts become a part of it." Hofmeister has demonstrated that the osteoclasts dissolve the bone in the usual process of lacunar absorption by the formation of carbonic acid.

The absorption of the iso-bone transplant may be brought about by the improper treatment of the osteoplastid. The preparation of the bed should, by all means, supersede the removal of the graft, which should be immediately transplanted with the least amount of manipulation possible. A small graft immersed in bichloride of mercury (1 to 50,000) for from three to five minutes, was always absorbed, likewise transplants which were handled with gloves washed in bichloride of mercury (1 to 2000) and rinsed in sterile water were absorbed. The transplantation bed showed evidences of necrosis after the use of bichloride of mercury during the operation. Placing the transplant into alcohol (1 to 20,000) for five minutes is very injurious to the graft and its use was always associated with the absorption of the graft. Freezing, while it has been successful with some tissues, has been unsuccessful in this series of experiments. Heat is very injurious to the viability of the transplant and has been the cause of not a few poor end-results, especially since the advent of the electric saw. A temperature of 160° F. has been recorded, on many consecutive trials, immediately after passing through three inches of compact bone and exercising considerable care (cold water, slow speed and frequent stops). If it is necessary to depend upon the bone cells in the periphery of the graft for its future viability, and there are sufficient indications at the present time to substantiate this view, then it is of paramount importance not to allow the saw to become heated. Many other antiseptic solutions, such as are found in the armamentarium of any well-equipped operating room, as mercury cyanide, formaldehyde, etc., were experimented with. They were invariably followed by absorption. Probably no antiseptic solution has as deleterious effect on living tissue as tincture of iodine. Even in extreme dilutions, absorption of the graft occurred. This, no doubt, is due to its power of penetration, which can be demonstrated by the starch reaction in deep sections. The reaction is obtained at a surprising distance from the surface. Under no circumstances should it be employed about the field of operation during the transplantation of bone.

Occasionally it must be admitted that even iso-bone will be absorbed in some animals just as hetero-bone is absorbed in the majority of untreated animals. Even hetero-bone has been known to remain in the human body for years (sheep to man) and perform its function.

THE FATE OF THE MEDULLARY ISO-BONE TRANSPLANT.[1]

The fate of the iso-bone transplant will be discussed, for convenience of explanation, under the seven following divisions:

A. The occasional early absorption of the osteoplastid.

B. The early tissue changes immediately adjacent to the osteoplastid.

C. Death of the bone cells within the osteoplastid.

D. The reëstablishment of a permanent circulation.

E. Methods of new bone deposition.

F. The metamorphosis of the entire osteoplastid into a complete osseous entity.

G. The final absorption of the osteoplastid.

Many of the following changes take place simultaneously and in some instances are dependent upon the formation of tissue complexes which may advance to more specialized differentiation.

A. THE OCCASIONAL EARLY ABSORPTION OF THE OSTEOPLASTID.

Occasionally the iso-bone transplant is absorbed in a very short time after transplantation. This early absorption is due, probably, to the sensitization of the recipient to the foreign proteid of the donor (production of specific ferments?). However, many other factors may be responsible for the early absorption of the osteoplastid, especially when such a delicate process as the transplantation of living tissue is involved. While some observers have recently claimed that the early absorption of either the isoplastid or the heteroplastid is due to "changed serological relation," nevertheless Lambert and Hanes have demonstrated that transplants are capable of maintaining their vitality, *in vitro*, under artificial incubation, in heteroplasm from species not too remote phylogenetically from the recipient. From these observations it is readily seen that the early absorption of the osteoplastid is not due to a lack of proper food material but rather to some inherent capacity of the cytological constituents of the blood or surrounding tissues of the host. These inherent properties of the recipient tissues, which produce such biochemical differences as to promote autolysis and absorption of the isoplastid, differ from the processes which cause the absorption of the heteroplastid. Isoplastic absorption is dependent upon the bloodvessels and stroma (Bashford) while heteroplastic absorption is brought about by a process of immunization and the action of the macrocytes.

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[1] The remarks apply only to a periosteal-free, compact bone transplant placed into the diaphysis, and does not refer to bone transplanted into cancellous tissue in proximity of the epiphysis.

More matured bone cells in the periphery of the graft will maintain their viability than in its central portion, therefore more absorption will occur in the central portion than in the peripheral portion. There will be less absorption per unit mass of the osteoplastid in a complete fibula transplant with the two surfaces of the compact bone in contact with the plasma of the host, than could be expected in a tibia transplant (crest) with only its external surface in contact with the plasms of the recipient. The fibula-plastid will require less absorption and replacement than a tibia-plastid, and therefore the immediate tissue reaction will cease earlier, viz., shorter convalescence.

B. THE EARLY TISSUE CHANGES IMMEDIATELY ADJACENT TO THE OSTEOPLASTID.

The irregular space between the bone of the recipient and that of the osteoplastid, where bone is in direct apposition to bone, will immediately become filled with coagulated blood and lymph. The clot, in due course of time, will undergo organization with the formation of islets of osteoid tissue (as at *A*, Fig. 8) through which new capillaries will push themselves to the osteoplastid and form a reticulum of fine, anastomosing capillaries around the osteoplastid. From this vascular network small capillaries are seen to enter the empty Haversian

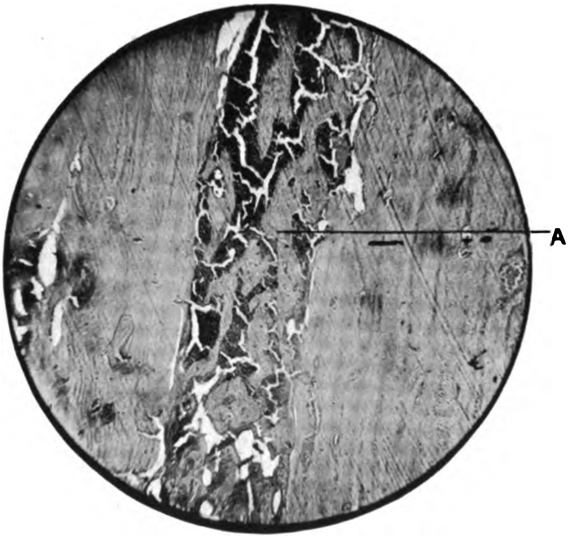

FIG. 8.—Medullary transplant into femur of a rabbit, seven weeks after transplantation. Osseous tissue of the recipient on the left, osteoplastid on the right, with islets of osteoid tissue deposited between them. Many capillary spaces are seen in the osteoid deposition.

canals. At both ends of the transplant a blood-clot will be formed, the size of which will depend upon the traumatism to the marrow substance. If the marrow substance has been injured by forcing the osteoplastid against it, producing undue pressure, further development of osteoid tissue at the ends of the osteoplastid are delayed until the proper equalization of pressure is produced by necrosis and absorption. If the marrow has been removed for a sufficient distance, so as to allow the introduction of the osteoplastid without producing unnecessary pressure atrophy and necrosis, the both ends of the transplant will be sealed off from the remaining marrow cavity by a blood-clot. This occurs within the first tweny-four hours. The endosteum, which has been previously removed from the medullary cavity by curetting, will proliferate and cover over the denuded bone as far as the blood-clot and later will extend across the concave surface of the clot, permanently sealing off the proximal and distal medullary cavities from the graft by a limiting layer of endosteal cells.

The blood-clot at either end of the graft will extend up farther on the sides of the medullary cavity than it does in the centre, producing a concave surface on the clot. The blood-clot after organization gradually undergoes a metamorphosis into osteoid tissue and in the case of a fibula transplant, the osteoid material forms a plug extending into the medullary cavity of the graft. The transformation of the end clots into osteoid material is accomplished much more quickly than the same formation of osteoid tissue at the sides of the graft, *i. e.*, between it and the compact bone of the host. The calcification of the osteoid deposit at the ends of the graft progresses quite rapidly, so that at the end of thirty days both ends of the graft are solid in the marrow cavity.

The space between the ends of the fractured fragments becomes filled with a blood-clot which finally organizes into ordinary connective tissue, but for some unknown reason does not undergo calcification and ossification until many months later. (Approximately seven to nine months in the tibia of a dog, and if conditions are not favorable this time is materially increased.) This delayed process of calcification is probably due to atrophy of the ends of the fractured fragments extending back from the ends a varying distance. Not until regeneration has been completed in these atrophied ends, does the cicatrix between the fragments undergo calcification and ossification.

The same process of delayed calcification takes place within the medullary cavity and is especially marked when the transplant is not fitted to the shape of the medullary cavity. In this case the edges of the graft under pressure undergoes necrosis and absorption until the pressure is equalized and compatible with the vitality of the surrounding living tissue. While the primary purpose of the medullary transplant is to immobilize the fragments, nevertheless any undue pressure between the transplant and the compact bone of the host will produce a delay in complete osseous union.

These processes of necrosis and absorption are retrogressive and are not compatible with regenerative and reparative processes. Not until these retrogressive processes have completely subsided is it possible for any process of a reparative nature to take place. This simply means a delay in a process which is of primary importance, being secondary only to immobilization and the proper coaptation of the fragments. Moreover, the process of absorption is dependent upon the physical condition of the patient and is commensurable with the variability of any such process in the human body. The end-products of pressure necrosis and degeneration act as a stimulus to osteogenesis, producing excessive callus formation which is consequently detrimental to the complete restoration of the function when the fracture is in proximity to a joint, causing limitation of motion.

The early formation of osteoid tissue in the space between the transplant and the adjacent osseous tissue of the recipient is primarily dependent upon the degree of apposition. A small space fills in more quickly than a large space. Secondarily other factors retard or even prevent entirely the ultimate deposition of true osseous tissue. Such tissues as muscle, fat, periosteum, endosteum, etc., probably also marrow (?), which occasionally may find their way between the compact bone of the host and the transplant will produce a cicatrix which will not become ossified but remain merely as a fibrous tissue union.

All the Haversian canals of the graft do not become revascularized, but some remain occluded with coagulated blood. The area of osseous tissue, which received its nutriment from such a canal, becomes necrotic and undergoes absorption. The irregular deposition of new bone in the graft is no doubt due to this condition. Such areas are eventually ossified by the method of "creeping replacement."

Finally the conformation of new osseous development is dependent upon the balanced action of the constructive osteoblasts and the destructive osteoclasts which, in time, produces dissolution of spicules of excessive osseous deposition.

Deposition of calcium salts in the osteoid plugs at each end of the transplant must not be mistaken on the interpretation of the röntgenograms for absorption of the graft since röntgenograms frequently taken will demonstrate that this area of decreased intensity is progressive and not retrogressive, as must be the case in peripheral absorption. At the end of the first few months after the transplantation, the medullary graft has increased in length and the tapering ends of the graft are due to the progressive deposition of calcium salts in the osteoid plugs which form soon after the introduction of the transplant.

C. DEATH OF THE BONE CELLS WITHIN THE OSTEOPLASTID.

During the normal metabolic activity of osseous tissue, the matured bone cells are constantly being replaced by osteoblasts which have reached the stage of complete maturation. Whether the lacunar space occupied by the worn-out bone cell is to be occupied by the new bone cell is not known, although taking into consideration the complicated structure of the bone cell with its ramifying fibrils extending through the canaliculi, it does not seem feasible that such a process of replacement were possible. All the stages of maturation are present at one time during the normal economy of osseous tissue metabolism, from the fibroblast to the fully differentiated bone cell. If this is the case in normal bone development we should at least be prepared to accept the same conditions for transplanted osseous tissue. In the osteoplastid we find bone cells in all stages of destruction, which continues at a greater rate than in normal osseous tissue. From the second to the tenth day there appears to be no limit to their destruction. However, in each cross-section many living bone cells are always found in the periphery of the graft, while in the central portion, the majority will be found shrunken and dead. Many lacunæ are completely devoid of any cellular life and the staining reaction of the calcified material in its neighborhood is the best guide for the interpretation of the death of the bone cell. Empty lacunæ do not necessarily mean dead bone cells, especially not with our present histological technic. Furthermore, it must be remembered that a few bone cells in the host, after curetting away the endosteum, will die, as already shown by Cotton and Loder. Occasionally after a bone cell has taken up its task of producing new bone in the transplant, as shown by the deposition of a few lamellæ of bone, the cell will be found shrunken and the staining reaction deficient. Evidently the bone cell did not have the necessary reserve force to hold out under such a difficult environment. The process of calcium deposition will immediately be assumed by another bone cell. The metabolic interchange in a transplant must necessarily be many times greater than normal to keep up with the increased tissue destruction and absorption.

D. The Reëstablishment of a Permanent Circulation.

The reëstablishment of a permanent circulation is one of the most important stages in the life of the transplant, since upon its timely completion depends either the continuance of its existence or death. Moreover, one of the earliest signs of absorption of the transplant is the lack of formation of new capillaries in the tissue adjacent to the transplant, as is constantly observed in the majority of heteroplastic transplants. Capillary proliferation immediately surrounding the transplant is an indication on the part of the recipient that the graft will be favorably received. While capillary proliferation is not seen in the majority of heteroplastic transplants, it occasionally takes place in the most remote species (pigeon to rat).

In normal bone the Haversian canals contain several types of tissues, *i. e.*, the small artery, a large vein, a very narrow lymph channel and cellular tissue. In the transplant, these structures are seldom seen. Lymph vessels and veins have not been observed at any stage after transplantation. The circulation of the graft is established by an ingrowth of capillaries into the Haversian system from the adjacent tissues of the host. The fine, capillary network, which is seen in the space between the transplant and the compact bone of the host as described above, sends fine capillaries into the substance of the transplant, wherever it is possible to gain entrance. They usually pass into the Haversian canals, thus restoring the greater part of the Haversian system by an ingrowth of capillaries from the tissues of the host. These small capillaries may enter the graft at crevices in the bone and this may occur in the immediate vicinity of a large Haversian canal. As a rule the great majority of the Haversian canals show newly formed capillaries, but some of them are filled up with a coagulated, structureless substance with no indications of blood-vessels.

In constant association with the new-formed capillaries are seen numerous large cells, which vary in morphology and are no doubt maturing bone cells. They are situated on the outside of the vessel wall sometimes, especially in large Haversian canals. They are in no relation to the bloodvessels, with the exception that they are invariably present. Occasionally these cells have been seen to occupy recesses in the calcified matrix at the side of the small capillaries. From these cells the Haversian lamellæ are deposited.

The reëstablishment of the circulation in a fibula transplant proceeds more rapidly than in a solid, compact osseous transplant. The capillary ingrowth proceeds both from the tissue surrounding the fibula and also from the reconstructed tissue of its marrow cavity. The capillary proliferation continues until the capillaries pass through the compact bone and finally ramify with the capillaries of the marrow tissue.

E. METHODS OF NEW BONE DEPOSITION.

The replacement of old bone by new bone during the normal metabolic activity of the osseous system is accomplished almost entirely by lacunar absorption and subsequent bone apposition. Living normal bone, like any other tissue, must constantly be replaced; it is not immutable. Likewise bone substitution is a constant process in transplanted bone, considerable new bone must be deposited to insure the continuity of the graft, since a portion of all transplanted bone becomes necrotic. These necrotic areas undergo gradual replacement by new bone. If the graft has been transplanted either with its endosteum or periosteum intact, some of the new bone will be derived from the activities of their respective osteogenetic layers. These cells can exert but little influence upon bone substitution within the central portion of the transplant. The specific osteogenetic cells are present in the Haversian system and can deposit new bone, but the methods of deposition are not entirely agreed upon. Axhausen maintains that lacunar absorption and subsequent lammellar deposition, as shown in Fig. 9, explain the method of replacement of all new bone. Other observers do not agree with him. Replacement of osseous tissue by direct contiguity is frequently observed—this is the so-called method of "creeping replacement" (Schleichender Ersatz). Necrotic tissue in direct contiguity with living bone, is gradually grown into by the young maturing osteoblasts which produce absorption of the necrotic bone and ultimately the deposition of new bone to replace it. Bone absorption and bone building are properties of developing and mature bone cells. Bone is absorbed with the liberation of carbonic acid (Hofmeister) setting free the earthy salts for the synthesis of new bone by the mature bone cells, as Wieder has demonstrated that new bone is not deposited until considerable cortical bone has undergone absorption.

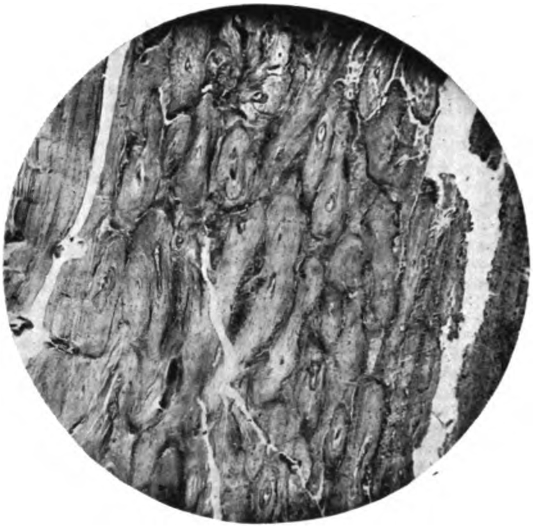

Fig. 9.—Osteoplastid, six months after transplantation, showing complete metamorphosis of the osteoplastid into an osseous entity, with the Haversian canals entirely surrounded by lamellæ of osseous deposition.

All necrotic bone becomes absorbed under the influence of the mature bone cells and new bone is deposited layer after layer by these same cells. This process is constantly being observed in all sections of transplanted bone. The maturing bone cells, in the immediate vicinity of the necrotic osseous tissue, will produce changes in the dead bone by its fibrils which penetrate the bone through the fine canaliculi and through their influence gradually initiate the process of absorption.

F. METAMORPHOSIS OF THE ENTIRE OSTEOPLASTID INTO A COMPLETE OSSEOUS ENTITY.

With the complete reëstablishment of the circulation and the deposition of new bone for the necrotic, calcium-saturated matrix, the osteoplastid becomes, after many months, an osseous entity directly continuous with the adjacent osseous tissue of the host. All osseous transplants will not progress to the same degree, since some transplants stimulate osteogenesis to a greater extent than others, producing a large callus sufficient to supply the necessary mechanical demands placed upon it. In such a case the early removal of any physiological demand would remove the necessity of the transplant, and its metamorphosis may be discontinued at any stage of transformation. The time necessary for the complete transformation of the osteoplastid depends upon the size of the graft, condition and age of the host, and will vary from one to two years.

G. FINAL ABSORPTION OF THE TRANSPLANT.

The transplant is not a permanent entity, since a gradual decrease in the functional demands is associated eventually with complete absorption of the graft. This is shown very early in transplants placed into the medullary cavity of the humerus for the repair of a recent fracture. In this location in a healthy individual all mechanical demands are early removed with a corresponding early absorption of the osteoplastid. In a case reported in a previous section of this book, the transplant is undergoing absorption as early as the fourteenth month after operation. Complete absorption will take place in from two to five years, depending upon the size of the graft, age of the patient, and the place of its insertion.

THE FATE OF THE OSTEOPLASTID TRANSPLANTED INTO CANCELLOUS BONE.

The histopathological changes in the osteoplastid transplanted into cancellous bone are identical with those changes observed in the osteoplastid transplanted into the medullary cavity of the compact bone. The constitutional structure of the bed differs essentially from the bed surrounding a medullary transplant. It is this cancellous structure which must be considered separately. The osteoplastid stimulates osteogenesis in the cancellous bone immediately adjacent to the transplant (as shown in Fig. 10), with the early formation of many new trabeculæ about the compact transplant. The new trabeculæ extends between the trabeculæ of the cancellous tissue, finally producing a more compact osseous structure. Where the area of cancellous tissue between the compact bone of the

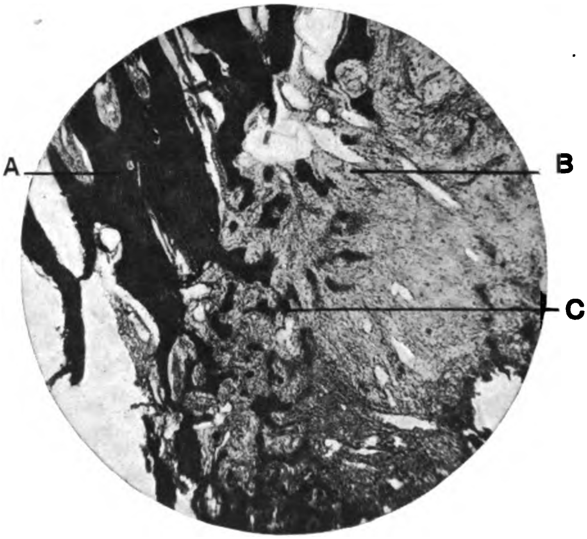

FIG. 10.—Compact bone transplant in the cancellous tissue of the head of the femur (human), twenty-three days after transplantation. Many new trabeculæ of bone deposited about the transplant. *A*, transplant; *B*, old trabeculæ; *C*, newly formed trabeculæ of bone.

transplant and the compact bone of the host is small, as in experimental animals (head of humerus in rabbit), the entire area becomes transformed into compact bone.

This new semicompact, cancellous structure is not permanent since there is no permanent physiological function which demands such compact cancellous tissue in this region. With a favorable functional result the recently produced compact bone together with the transplant will eventually undergo complete absorption.

SUMMARY.

Osteogenesis is dependent upon the maturation of connective-tissue cells into bone cells. Mother cells, capable of differentiation into osseous tissue, are scattered throughout the entire structure of bone, *i. e.*, in the Haversian system, in the periosseous osteogenetic layers, especially surrounding the bone and to some extent in the layers about the medullary canal. In the light of the recent pathological studies on the formation of heterotopic bone in the walls of blood-vessels, etc., it is hardly probable that the osteoblast is a specific cellular entity. Osteogenesis is not dependent upon bony contact, but for practical purposes, it doubly insures favorable end-results.

The most that can be expected in the transplantation of an osseous graft, large enough for practical purposes, is the continued development of the implanted osteoblasts, together with such stimulus as may be obtained from the osteoblasts of the host and the retention of viability in some of the implanted bone cells with their corresponding intercellular calcium matrix.

The continued existence of the transplanted bone is dependent upon its function in the human economy. It will exist and develop only as long as there is sufficient physiological demand for its presence. With the removal of these demands, the transplanted bone will eventually undergo complete absorption. Lack of physiological demand is associated with atrophy and absorption.

In the presence of an infection, the transplanted bone acts like any other tissue, *i. e.*, it may or may not withstand the toxic assault. A portion of the graft may undergo necrosis and sequestration, necessitating its removal.

CHAPTER IV.

INDICATIONS FOR AUTOPLASTIC BONE SURGERY.

AUTOPLASTIC bone surgery is becoming recognized as a satisfactory and dependable method of repairing skeletal defects of the human body whether congenital, the results of traumatism, or disease.

Autoplastic transplantation of bone is indicated with certain limitations, in the treatment of the following conditions:

I. Recent simple fractures.
II. Ununited fractures.
III. Tuberculous spondylitis.
IV. Congenital defects and deformities of bones.
    1. Spina bifida.
    2. Dislocation of the hip.
    3. Talipes equinovarus.
    4. Nasal deformities.
    5. Cranial defects.
    6. Deficiencies of long bones.
V. Acquired defects and deformities of bones.
    1. Diaphysial defects.
    2. Epiphysial defects.
    3. Nasal deformities.
    4. Cranial defects.
    5. Mandibular defects.
VI. Spondylolisthesis.
VII. Separation of the sacro-iliac synchondrosis.
VIII. Flat-foot.
IX. Arthropathy.
    1. Knee-joint.
    2. Ankle, tarsal, and vertebral joints.
X. Recurrent hernia.
XI. Trifacial neuralgia.
XII. Deformity of the female pelvis.

I. RECENT SIMPLE FRACTURES.

Autoplastic repair of recent simple fractures is indicated when internal fixation of the fragments is required.

Simple fractures may be divided for clinical purposes into three groups:

1. Those fractures in which good functional and anatomical end-results can be attained by external reduction and external immobilization. Open operation of any kind is contra-indicated in this very large group of fractures.

2. Those fractures in which it is necessary to expose the fracture by incision to effect proper reduction, but which, when once reduced, can be safely and securely immobilized by external methods.

3. Those fractures in which it is necessary to expose the fracture by incision to effect proper reduction, and which require both internal alignment, fixation and external immobilization to secure satisfactory end-results.

Autoplastic Repair is Indicated in the Third Group of Fractures.—Autoplastic fixation is indicated where it is difficult or impossible by manipulation and external immobilization to replace and retain the fragments in such apposition and alignment that good anatomical and functional end-results will be produced in a reasonable time and where simple open reduction cannot be securely maintained by external splints.

The following types of simple fractures of the long bones will most frequently show clear indications for this form of reparative operation:

Fracture of the Anatomical Neck of the Humerus.—Autoplastic fixation is indicated as the primary treatment in unimpacted fractures of the anatomical neck of the humerus. If there is displacement of the small fragment it cannot be replaced and held in position by external means. The fragments unite in malposition with resulting limited motion of the shoulder or else the small fragment dies from loss of vascular supply and becomes a foreign body in the joint.

FRACTURE OF THE SURGICAL NECK OF THE HUMERUS.—Autoplastic fixation is indicated in fractures of the surgical neck when it is impossible to secure and maintain accurate reduction and alignment by external means. The fragments override in such a manner that reduction with good alignment is difficult or impossible to maintain, because of the contractions of the pectoralis major, latissimus dorsi, deltoid and other muscles drawing the lower fragment out of position. Rotation coaptation is difficult and often impossible to attain, because of rotation of the upper fragment, produced by the turning action of the muscles attached to the tuberosities. Unless there are irregularities of the fracture to mark the relationship of rotation of the fragments, accurate reduction can scarcely be accomplished except by open operation.

FRACTURE DISLOCATION OF THE SHOULDER.—Open operation with direct reduction of the dislocation, followed by immediate autoplastic fixation of the fracture, is indicated. The dislocation can rarely be reduced by manipulation and is usually treated expectantly or by excision of the dislocated fragment, with the resulting loss of function of the extremity.

FRACTURE OF THE SHAFT OF THE HUMERUS.—Autoplastic fixation is indicated in oblique and spiral fractures of the shaft of the humerus and also in transverse fractures, in individual cases where external appliances do not hold the fragments in good reduction. Immobilization of the fragments by external means is difficult to obtain without overriding of the fragments and shortening of the arm, because: (*a*) the humerus has no parallel supporting bone; (*b*) the contraction of the muscles extending from the shoulder across the fracture to the lower fragment; (*c*) the fracture is often oblique, spiral or comminuted.

FRACTURE OF THE HUMERUS THROUGH THE CONDYLES.—Autoplastic fixation is indicated when reduction by external means does not accurately replace the condylar fragments. Imperfect reduction of the condylar fragments changes the angle of motion in the elbow-joint, resulting in loss of the carrying angle. Displaced joint surfaces, projecting fragments and excessive callus result in restricted motion of the elbow-joint.

FRACTURES OF THE SHAFTS OF THE RADIUS AND ULNA.—Autoplastic fixation is indicated when there is irremediable overriding or displacement of the fragments, or when both bones are impacted in deformity, as in automobile-cranking fractures.

FRACTURE OF THE FEMUR.—Fractures of this bone present the greatest difficulties in treatment of any of the long-bone fractures, with the poorest average results in functional recovery when reduction is attempted by traction, manipulation and maintained by extension and external splints. The powerful muscles extending from the pelvis to attachments below the fracture, the shape of the femur and the strong leverage of the lower fragment, all tend to prevent the immobilization and retention of the reduction for sufficient time to obtain satisfactory end-results.

FRACTURE OF THE NECK OF THE FEMUR.—Autoplastic fixation of fractures of the neck of the femur is indicated as the primary treatment when the age, condition or environment of the patient do not contraindicate operation. The treatment of unimpacted fractures of the neck of the femur by position, extension and external immobilization, the method in common use, rarely reduces the fracture, does not completely immobilize the fragments and is not usually productive of satisfactory functional end-results.

When the upper fragment is displaced, its position cannot be controlled with any degree of certainty by traction and contratraction, manipulation or position of the extremity. In the majority of cases the upper fragment can be replaced in accurate approximation with the lower fragment only by direct open reduction and can be immobilized in that position only by direct fixation to the lower fragment.

It is to be regretted that so large a proportion of fractures of the hip occur at an age of life and condition of health that prohibit any operative procedure, and recover with or without expectant treatment of the fracture, with deformity, fibrous union and diminished functional activity.

INTERTROCHANTERIC FRACTURE OF THE FEMUR.—Autoplastic fixation is indicated as the primary treatment, because it is evident that the fragments cannot be placed in normal rotation and alignment except by direct, open, forcible reduction and cannot be immobilized in reduction except by direct fixation of the fragments. When the line of fracture is between the greater and lesser trochanters, the upper fragment is rotated and drawn upward, backward and outward by the muscles attached to the greater trochanter, while the lower fragment is rotated and drawn upward by the iliopsoas and the mass of muscles crossing the line of fracture. The fragments override at an angle. Direct apposition of the fracture by external manipulation is not possible.

SUBTROCHANTERIC FRACTURE OF THE FEMUR.—Autoplastic fixation is indicated as the primary treatment, because it is impossible to sufficiently control the short fragment to effect proper reduction and bone alignment by external means. The deformity of this injury is produced largely by the position of the short upper fragment, which is flexed, abducted and rotated by the iliopsoas muscle, the lower fragment overriding. The short fragment is not well controlled by external methods.

FRACTURE OF THE SHAFT OF THE FEMUR.—Primary treatment by autoplastic fixation is indicated, without attempts at other methods of fixation, in oblique and spiral fractures of the shaft of the femur, as it eliminates the necessity of extension by weights and pulleys with its discomforts and uncertain end-results.

It is difficult to obtain immobilization of the fragments by external appliances in fractures of the shaft of the femur, without overriding of the fragments and shortening with deformity of the thigh because:

(*a*) The fracture is usually oblique or spiral and sometimes comminuted.

(*b*) The femur has no parallel supporting bone.

(*c*) The small diameter of the shaft compared with the length of the bone.

(*d*) The anteroposterior curve of the shaft.

(*e*) The irregular offset of the head and neck throwing the centre of gravity of the entire extremity away from the axis of the bone.

(*f*) The powerful leverage of the lower extremity below the fracture.

(*g*) The contractions of the powerful muscles extending from the pelvis across the fracture to the lower fragment.

(*h*) Spiral fractures cannot be held in continuous reduction by external immobilization, because of the action of the muscles in drawing up the lower fragment, producing a screw effect between the ends of the fragments, ending in rotation and shortening of the extremity.

Supracondyloid Fracture of the Femur.—Occasionally fractures about the condyles show displacements and sometimes encroachments upon the knee-joint which cannot be relieved except by open manipulation and direct fixation. Autoplastic repair is then indicated.

Fracture of the Tibia.—Autoplastic fixation is indicated in fracture of the tibia in which treatment by external reduction has failed. Spiral fracture of the tibia is usually produced by torsion and bending of the leg. It usually occurs at the junction of the middle and lower third of the shaft and when accompanied by an impacted or interlocking fracture of the upper part of the fibula, is not an uncommon condition. Reduction is rarely possible except by open operation with surgical fracture of the fibula at the same level, while immobilization can rarely be accomplished except by direct internal fixation. Spiral and oblique fractures of the shaft of the tibia, with fracture of the fibula at nearly the same level, are very difficult fractures to immobilize in the correct position, and demand open autoplastic fixation.

Contra-indications.—Autoplastic fixation is contra-indicated during the period of bone growth in fractures of long bones in which the epiphyses are implicated, as the transplant will stimulate osteoblastic activity with early bony union between the epiphysis and the diaphysis, checking the growth of the bone.

Autoplasty is contra-indicated in the presence of the grave constitutional conditions which prohibit any operative measures, except as life-saving procedures. It is also contra-indicated in the aged, where the shock of operation and the affects of anesthesia seriously endanger life.

Autoplastic repair of fractures is not indicated in that large proportion of recent simple fractures of long bones which may be reduced by external means and safely immobilized in good position by external splints and appliances or in those fractures which require open reduction, but which can be securely and safely held in reduction by external means.

Autoplastic fixation should not be considered a routine operation for the treatment of recent simple fractures, but should be reserved for the treatment of those fractures of long bones which show poor end-results by other methods of treatment, and for those individual cases which do not respond to treatment without internal fixation.

Autoplastic repair of recent fractures is particularly dangerous when attempted by novices in aseptic surgery or in places where complete aseptic surroundings cannot be obtained.

Compound Fracture.—The treatment of a compound fracture should be as near the treatment of a simple fracture with a similar injury to the bone as the complications of an open wound will allow.

Every compound fracture should be regarded as an infected wound until sufficient time has elapsed to demonstrate the absence of suppuration. In a good proportion of cases the bacteria-resisting properties of the tissues will overcome any infection that may have been introduced into the wound at the time of the injury and the wound goes through the process of healing without suppuration. Autoplastic transplantation of bone is contra-indicated in the presence of infection and should not be attempted in the treatment of compound fractures unless the surgeon is positive that the wound has not been contaminated or until time has elapsed to prove its sterility.

II. UNUNITED FRACTURES.

In the physiological process of the healing of bone after recent fracture, when complete reduction has been accomplished, there are four stages of repair which must occur at the proper time, in their correct sequence and with normal force to produce stable anatomical and functional results:

(*a*) The formation of the provisional callus.

(*b*) The penetration of the provisional callus by the osteoblasts.

(*c*) The deposition of calcareous salts around the osteoblasts.

(*d*) The absorption of excessive functionless bone.

Any deviation or failure in these stages of repair, no matter what the producing element may be, endangers the ultimate union of the fracture.

Other conditions may be associated in determining defective union of fractures:

(*e*) Defective reduction in which the fragmented surfaces of bone are not placed sufficiently in apposition for bone repair to bridge the defect.

(*f*) Defective immobilization in which the fragments are not retained in stable apposition or are allowed too much motion.

(*g*) Interposition of fluid, muscle, fascia or fragments of detached bone.

(*h*) Defective blood supply from injury to the nutrient artery, pressure from tight bandaging or separation of fragments by comminution.

(*i*) Disturbance of the trophic nerve supply.

(*j*) Fixation by foreign bodies, as metal plates, wire sutures, steel and ivory nails, screws, dowels, etc.

(*k*) Local malignant and tuberculous diseases of bone.

(*l*) Infection and suppuration.

(*m*) General constitutional bone diseases.

(*n*) Exhausting and debilitating constitutional diseases or conditions.

Ununited fractures are usually classified in three groups, according to the condition of the ends of the fragments and their relationship to each other.

1. Delayed Union of Fractures.—The time is relative when the physiological repair of fractures become delayed union or when delayed union becomes non-union. If the usual time required for a fracture to unite has passed and solid bony union between the fragments has not resulted, delayed union is said to exist. After an indefinite time the delayed union may become solidly united or may result in non-union. In delayed union it is usual to find that the callus has ensheathed the ends of the fragments and united them, but has remained soft. The osteoblasts, liberated from the fragments by the injury and subsequent changes, have failed to penetrate and fill the callus with the active elements of new bone, or have failed to stimulate the deposition of calcareous salts in the callus at the proper time. The physiological ossification of the callus does not result in the presence of these conditions.

The indications for treatment of delayed union by autoplastic bone grafting before sufficient time has elapsed to eliminate the possibility of bony union by delayed natural processes, depend upon the conditions surrounding the patient and the urgencies of early solid bony union. If time and early substantial bony union are not of great importance to the patient, because of the location of the fracture, the vocation or social surroundings of the patient, liberal time for delay is advisable to give opportunity for late bony union. But if the patient is a wage-earner by his physical efforts, it becomes an economic problem for those responsible for his treatment to restore his self-sustaining ability and working capacity as an industrial unit at the earliest time consistent with safety.

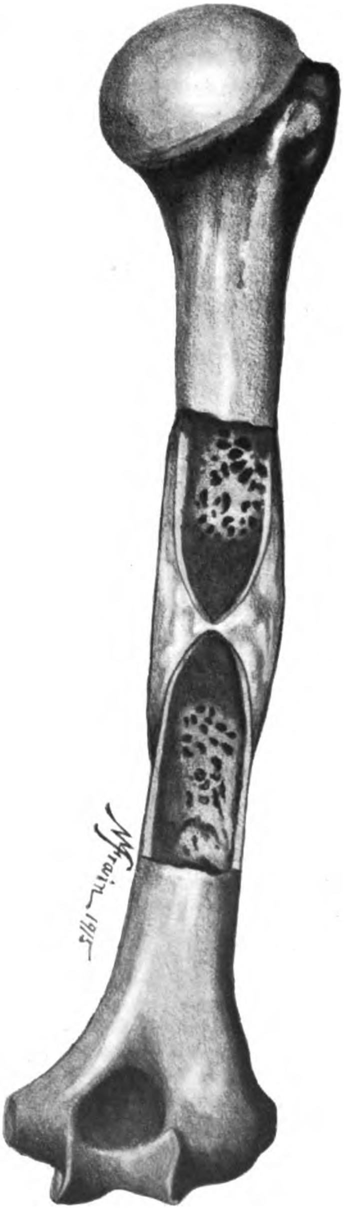

Fig. 11.—Fibrous union of fracture of the humerus.

Autoplastic grafting of fresh bone when properly applied under good conditions will cause solidification in the area of delayed union. It is indicated at a time to be determined by the judgment of the surgeon in the individual case.

2. Fibrous Union of Fractures.—In this variety of ununited fractures the soft callus has failed in its ossification, has atrophied and remains as a fibrous band uniting the fragments (Fig. 11). From some unknown cause the osteoblasts within and around the ends of the fragments become imprisoned by the deposition of calcareous salts before they have completely penetrated the soft callus between the ends of the fragments, thus prematurely ending the process of ossification. The ends of the fragments in fibrous union are more or less absorbed, rounded and usually covered with a dense fibrous tissue resembling perios-

teum and are connected by strong fibroligamentous bands. A longitudinal section of the fragments shows the medullary cavity to be obliterated at the ends by hard, brittle, sclerotic callus, in which the lime salts are in excess. Another condition occasionally supervenes in fibrous union in which absorption is the predominating factor. The fragments become thin, pointed, widely separated and the fibrous band of union becomes attenuated or entirely eliminated (Fig. 12).

Autoplastic grafting of live bone across the defective area is indicated in fibrous union of fractures, to unite the fragments by a bridge of fresh bone, to stimulate the production of osteoblasts with the formation of new bone in the defect and around the transplant, connecting the fragments by a deposition of new bone.

3. PSEUDARTHROSIS.—This form of ununited fractures resembles a ball-and-socket joint (Fig. 13). The ends of the fragments are rounded, one, at the expense of the outer border, making a convex surface, and the other, at the centre, making a concave surface. The surfaces in contact are smooth, polished and either eburnated or covered with thin cartilage. The ends of the fragments are surrounded by a ligamentous capsule containing a bursa with fluid resembling synovial fluid. Longitudinal section of the fragments shows sclerosis of the ends forming the false joint and obliteration of the medullary canal by hard, brittle callus.

The indication for treatment consists in the destruction of the surfaces of the false joint and autoplastic transplantation of live bone across the defect well into healthy bone in each fragment, directly uniting the fragments by a bony bridge, coincidently stimulating osteogenesis between the fragments. The autoplastic bone graft should be used in the treatment of any fibrous union or pseudarthrosis without delay or previous trial of conservative methods.

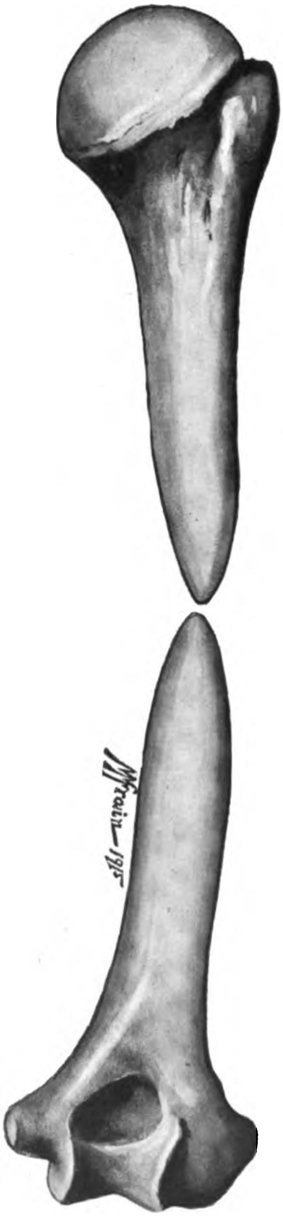

FIG. 12.—Failure of union in fracture of the humerus, with atrophy of the fragments.

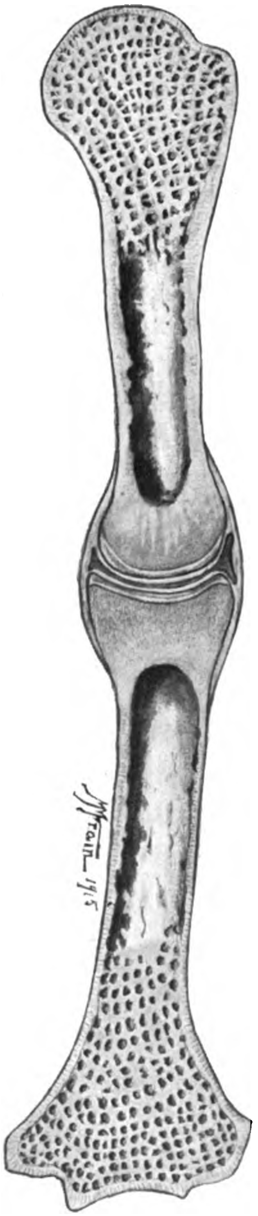

FIG. 13.—Pseudarthrosis of the humerus.

Autoplastic grafting in ununited fractures is absolutely contra-indicated in the presence of infection and should not be attempted following infection or suppuration of bone until all danger of liberating latent pyogenic germs has passed. Three months at least should intervene before the grafting operation can be safely performed.

Autoplastic bone grafting is plainly indicated in the following specific locations in the treatment of ununited fractures:

1. Shaft of the clavicle.
2. Shaft of the humerus.
3. The olecranon process.
4. Shaft of radius or ulna.
5. Phalanges.
6. Neck of the femur, when the small fragment consists of living bone of sufficient integrity to be of functional value when reunited to the shaft.
7. Shaft of the femur.
8. Patella.
9. Shaft of the tibia or fibula.

III. TUBERCULOUS SPONDYLITIS.

In health the vertebral column is extremely mobile, depending for its mobility upon the joints between the articular processes, the elastic intervertebral fibrocartilages and the leverage established by the muscles of the back acting upon the spinous and transverse processes. Motion between the vertebral bodies is very constant, accompanying almost every movement of the body and every respiratory excursion. Each movement produces a change of pressure between the vertebral bodies. When these structures are attacked by the disintegrating process of tuberculous disease they come together with increased force due to the irregularity of the diseased surfaces and the muscular spasm, producing traumatism which increases the destructive action of the disease.

The treatment of Pott's disease by immobilization of the diseased vertebræ is the accepted method of treatment. Permanent fixation of the tuberculous segment of the spinal column can be safely and quickly accomplished by autoplastic procedure.

Autoplastic immobilization of the vertebræ is indicated in practically every case of active tuberculous spondylitis, to relieve muscular spasm and pain, to limit the progress of the disease and to hasten its resolution by preventing motion between the diseased vertebræ, traumatism and crushing of the tuberculous areas. It is indicated to limit or correct the kyphosis either at the time of operation or by aftergrowth of the spinal column. It is indicated for the relief of the complications of the tuberculous process, as psoas abscess, cold abscesses, paraplegia, etc. It is especially of value in tuberculosis of vertebræ in the thoracic region, as immobilization against respiratory motion is impossible by other means. It is indicated at any age of the patient or condition of the disease where immobilization will aid in relief of the symptoms, when the physical condition of the patient will allow the necessary operative procedure.

IV. CONGENITAL DEFECTS AND DEFORMITIES OF BONES.

1. Spina Bifida.—The bony defect in spina bifida is caused by the failure of fusion of the neural arches during fetal development.

Autoplastic transplantation of bone is indicated in the treatment of this condition, to close the congenital bone defect and to strengthen the weakened vertebral column in those cases where the spinal hernia can be controlled or replaced by operation. When there is serious failure in embryological development of nervous structures, as shown by paralysis of the parts supplied by the cauda equina, operation is contra-indicated. Hydrocephalus is also a contra-indication to the operation. Transplantation of bone is indicated in the primary operation for the treatment of operable cases of spina bifida. It is also indicated as a secondary operation where the meningocele has previously been controlled and where there exists a large, bony defect, with weakness producing lordosis or other deformity.

2. CONGENITAL DISLOCATION OF THE HIP.—In congenital dislocation of the hip, the acetabulum is always present in the normal location, but it is poorly developed, ill-shaped, shallow and partly filled with soft tissues. With the dislocation of the head of the femur, the capsule of the joint becomes a suspensory ligament, sustaining the weight of the body in walking. It becomes thickened and stretched as the head of the femur changes from the acetabulum in weight-bearing.

Autoplastic remodelling of the upper rim of the acetabulum is indicated in those cases of congenital dislocation of the hip in children in whom conservative mechanical treatment without incision has failed, when deficiency of that part of the acetabulum is shown by the röntgenogram. Remodelling of the capsule by plaiting, reefing and, when necessary, by incision and suture is indicated as supplementary to the remodelling of the acetabulum.

3. TALIPES EQUINOVARUS.—Autoplastic remodelling of the tarsal bones is indicated to remedy the deformity in the more severe types of congenital club-foot, complicated by serious deformity of bone, in adults, adolescents and older children who have resisted tenotomies and forcible correction or have relapsed after operation.

4. NASAL DEFORMITIES.—Autoplastic remodelling of the bridge of the nose is indicated in severe pug-nose and congenital saddle-nose when the irregularity is of sufficient importance to the individual to demand operation.

5. CRANIAL DEFECTS.—Autoplastic transplantation of bone is indicated in congenital defects and deficiences of the cranium when the defect exposes the brain to injury or produces symptoms of cerebral irritation.

6. DEFICIENCIES OF LONG BONES.—Filling of congenital defects and deficiencies in long bones by autoplastic transplantation is indicated to give shape, strength and function to the extremity, unless the character of the deformity is a contra-indication.

V. ACQUIRED DEFECTS AND DEFORMITIES OF BONES.

1. DIAPHYSIAL DEFECTS.—Autoplastic transplantation of bone to replace the whole or part of a diaphysis, which has undergone destruction by any of the following conditions, is a well-established procedure:

(*a*) *Traumatic Injuries.*—When a portion of the diaphysis of a long bone has been completely destroyed and removed by traumatism or so seriously injured that its vitality is lost and its removal becomes necessary, transplantation of bone into the defect is indicated. The length and shape of the extremity should be maintained until the wound has healed and until all danger from latent pyogenic microörganisms has passed before the plastic operation is done.

(*b*) *Acute Osteomyelitis.*—When a complete segment of the diaphysis of a long bone has undergone necrosis and sequestration from acute suppurative osteomyelitis, transplantation of bone into the resulting defect is indicated. The transplantation should be delayed until sufficient time has elapsed for the operative area to become free from pyogenic infection, after sequestration of the bone and complete healing of all suppurating wounds has occurred.

(*c*) *Tuberculous Osteomyelitis.*—When a complete segment of the diaphysis of a long bone has undergone tuberculous degeneration, removal of the diseased bone, followed by transplantation of healthy bone into the defect is indicated. When the area affected by tuberculosis is free from pyogenic infection the tuberculous bone should be removed and fresh, healthy bone grafted into the defect at the same operation. When there is infection by both tuberculous and pyogenic organisms the diseased bone should be removed, and the suppurating wound allowed to heal, before any attempt is made to close the defect. At a subsequent operation, after all danger of pyogenic reinfection has passed, the defect should be remedied by transplantation of bone.

(*d*) *Syphilis.*—When a complete segment of the diaphysis of a bone has been destroyed by gummatous osteomyelitis, removal of the diseased part is indicated, followed as a step of the same operation by replacement with healthy bone.

(*e*) *Benign Neoplasms.*—When a complete segment of the diaphysis of a long bone has undergone degeneration by reason of the growth of a bone cyst or other non-malignant neoplasm, excision of the neoplasm, with transplantation of bone into the resulting defect is indicated. The preservation of the overlying periosteum with its muscular and tendinous connections with their appropriate attachment around the transplant is also indicated.

(*f*) *Malignant Neoplasms.*—In the milder forms of malignant disease of the diaphysis, such as giant-cell sarcoma or circumscribed, large spindle-cell sarcoma, the indication is for early, complete excision of the diseased bone, together with its periosteum and musculotendinous attachments, followed by immediate transplantation of bone into the defect to replace the bone destroyed by the disease.

2. EPIPHYSIAL DEFECTS.—The defects of the epiphyses which enter into articulations are produced by the same conditions and diseases that produce diaphysial defects in the same bones, modified by the vascular cancellous tissue of the epiphysis and by the mobility of the articulation.

(*a*) Autoplastic transplantation of bone is indicated when the epiphysis of one bone entering into a joint has been destroyed, while the opposite articular surface remains intact. For example, when the head of the humerus has been destroyed by operable sarcoma or bone cyst, the indication is for excision of the diseased part of the humerus and transplantation of the upper part of the fibula into the defect, with the articular surface of the fibula in the glenoid cavity, reproducing an enarthrodial joint.

(*b*) In disease of joints in which excision of the joint is indicated to remove the disease, stable ankylosis is quickly produced by transplantation of bone across the resection. For example, resection of the knee-joint for adult tuberculosis, with transplantation of bone from the crest of the tibia across the resection.

3. NASAL DEFORMITIES.—Autoplastic transplantation of bone to remodel the bridge of the nose is indicated in depressed deformities produced by old, neglected fractures which do not respond to mobilization and replacement of the nasal bones. It is also indicated in old, depressed deformities in which there has been great destruction of bone, with collapse of

the bridge, due to congenital or acquired syphilis, tuberculosis, burns or pyogenic infection.

Transplantation of bone for deformity produced by disease should not be done until after recovery from the causative disease.

4. CRANIAL DEFECTS.—Autoplastic transplantation of bone to close acquired defects of the skull is indicated as follows:

(*a*) When deficiency of the cranial wall, resulting from destruction of bone by previous injury or disease, exposes the brain to external injury or irritation, as in the healed defect caused by compound fracture or operation on the skull, with removal of a portion of the cranial vault, autoplastic repair for protection of the brain should be done as soon as the local conditions will allow, without waiting for brain symptoms.

(*b*) When operation for lesion or tumor of the skull requires removal of a portion of the cranial wall of an extent sufficient to leave a defect exposing the brain to external injury, autoplastic repair should be done at the primary operation if not contra-indicated by shock or infection.

(*c*) When an old, depressed fracture of the skull, which is irritating the brain, requires removal for the relief of pressure, autoplastic repair after removal of the depression should be done to prevent overgrowth of bone into the cranial defect with consequent pressure and irritation of the brain with recurrence of the symptoms.

5. MANDIBULAR DEFECTS.—Autoplastic transplantation of bone is indicated to remedy defects of the lower jaw, produced by operation, accidental injury or disease. Suppuration is a contra-indication and the transplantation must be delayed until healing has occurred.

VI. SPONDYLOLISTHESIS.

Autoplastic transplantation of bone to produce bony fixation between the last lumbar vertebra and the sacrum is indicated in the treatment of spondylolisthesis, when the displacement is recurrent or continuous and accompanied by weakness in the back, pain and irritation of the cauda equina.

VII. SEPARATION OF THE SACRO-ILIAC SYNCHONDROSIS.

Autoplastic grafting of bone between the sacrum and ilium to produce fusion of the posterior parts of these bones and ankylosis of the articulation is indicated in separation of the sacro-iliac synchondrosis, when the accompanying loss of function is sufficient to demand operative procedure.

VIII. FLAT-FOOT.

When non-operative methods have failed to give relief in the treatment of flat-foot, a new supporting ligament may be built across the tarsal articulations by transplantation of periosteum.

IX. ARTHROPATHY.

1. Knee-joint.—In infantile paralysis when permanent damage to muscles and ligamentous structures has been such as to require the indefinite use of apparatus to prevent deformity and secure function of the knee-joint, Hibbs recommends stiffening of the joint by transplanting and grafting the patella between the articular surfaces.

2. Ankle, Tarsal and Vertebral Joints.—When these joints are affected by paralytic changes, ankylosis in the corrected position by transplantation of bone is indicated as an aid to other orthopedic measures.

X. RECURRENT HERNIA.

Trendelenburg[1] recommends reinforcement of the abdominal wall by flaps of periosteum and bone for recurrent femoral and inguinal hernia, when accompanied by great relaxation or deficiency of the adjacent abdominal wall.

XI. TRIFACIAL NEURALGIA.

Kanavel[2] tentatively suggests the obstruction of the trifacial foramina or canals by the transplantation of bone after avulsion of the nerve.

Bony obstruction to prevent regeneration of the nerve is not indicated in those patients on whom intracranial operation can be done with safety.

XII. DEFORMITY OF THE FEMALE PELVIS.

Based on animal experimentation, Smith[3] suggests the permanent enlargement of the contracted pelvic outlet in the female by autoplastic transplantation of a wedge of bone into the symphysis pubis.

By this scheme he believes it possible to increase the conjugate diameter of the pelvis from 1.5 to 2 cm. This amount of enlargement would be sufficient to at least relieve a certain class of border-line cases which are now subjected to operative obstetrics.

CHAPTER V.

INSTRUMENTS, TECHNIC, AND TRANSPLANT.

INSTRUMENTS.

A FEW special instruments are required in the execution of the technic in autoplastic bone surgery. Electric motor-driven instruments are almost a necessity in the proper transplantation of bone. They cut quickly, accurately, and with little shock. The elements of time and shock often decide between success and failure in the operation. While bone cutting can be done entirely by hand instruments, the execution is difficult, slow and inaccurate. The hammer and chisel traumatise the surrounding bone, produce shock and are followed by soreness and pain.

The author's assemblage of electrically driven instruments for use in the transplantation of bone is as follows:

1. SINGLE SAW.—A circular saw, 3 cm. in diameter, mounted on a short, stiff shaft (Fig. 15). The teeth are cross-cut and set so that the saw will cut freely through fresh bone without binding or producing frictional heat of sufficient intensity to endanger the vitality of the superficial cells of the transplant. Frictional overheating of the bone should be prevented by the set, sharpness and speed of the saw and not by the use of water or saline solution. The use of water for cooling the saw washes away the blood and serum needed for the immediate nutrition of the transplant. This saw is useful in removing transplants from almost any location. When fitted to a swivel hand-piece, it will cut in any direction and

at any angle. It is the saw which is most generally useful in autoplastic transplantation of bone.

2. Parallel Saws.—Two circular saws placed parallel to each other on the same shaft (Fig. 14). The blades are alike and interchangeable with the single saw. The distance between the blades can be changed to suit the needs of each location by means of brass washers, a series of which accompanies the saws. This combination of saws is useful in removing transplants when two sides are cut parallel to each other and in preparing the recipient bone to receive transplants shaped in this manner.

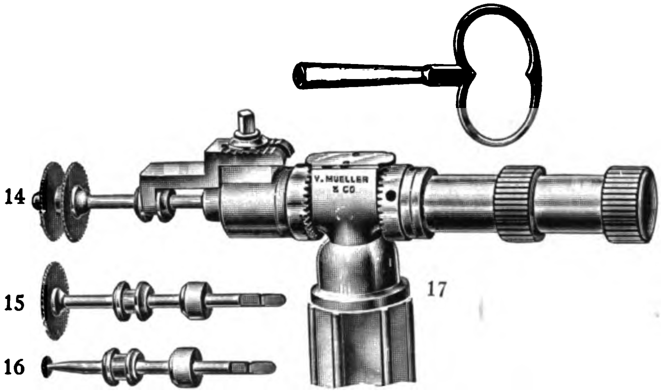

Fig. 14.—Parallel saws. Fig. 15.—A single saw.
Fig. 16.—Single small saw. Fig. 17.—Martel's hand-piece.

3. Single Small Saw.—A circular saw, 1 cm. in diameter, with heavy cross-cut teeth (Fig. 16). It is useful to cut across the ends of narrow transplants or gutters, the sides of which have been cut with the parallel saws, without overcutting and weakening the bone.

Fig. 18.—Electric reamer.

4. Reamers.—An electric reamer, 1 cm. in diameter, is needed for occasional use in trimming bone cavities for the reception of transplants (Fig. 18).

5. **Drills.**—Electric drills of various sizes are necessary for making holes, both in the transplant and the recipient bone, for kangaroo-tendon strands to secure the transplant in position (Fig. 19).

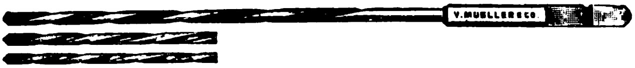

Fig. 19.—Drills.

6. **Electric Motors.**—There are two types of electrically driven engines for propelling surgical instruments in use:

(*a*) A motor from which the power is transmitted to the instruments by means of a heavy, flexible, metal cable. This arrangement permits the use of a motor with ample graduated power, which runs slowly and does not easily get out of order. It has the disadvantage that the cable interferes with the freedom of movement of the surgeon and that the position of the motor must sometimes be changed during an operation.

(*b*) A small, portable motor to which the instruments are directly attached. This motor has the great advantage of mobility, as the surgeon uses it directly as a hand-piece without the intervention of a cable and his movements are limited only by the electrical cord connection. It has the disadvantages of a small motor. The small size and limited power require that it be run at high speed and reduced by gear mechanism to obtain power to operate the instruments.

Either type of motor should be provided with a foot switch giving the surgeon accurate control of the power.

The assemblage used by the author consists of:

Kimble's Electrically Driven Engine.—It is a substantial motor of one-half horse power with a regulated speed and ample power for any emergency (Fig. 20).

Martel's Flexible Metal Shaft.—This shaft conducts the power from the motor to the hand-piece (Fig. 21).

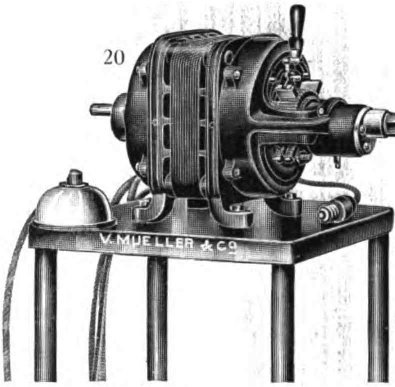

FIG. 20.—Kimble's electric engine.

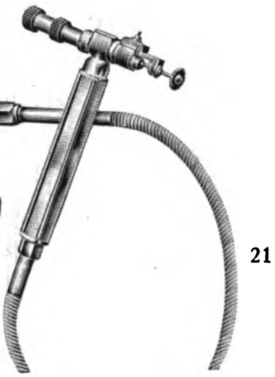

FIG. 21.—Flexible metal shaft.

Martel's Hand-piece.—The instruments are attachable to this hand-piece. It is geared to a swivel in such a manner that the instrument can be turned in different directions (Fig. 17).

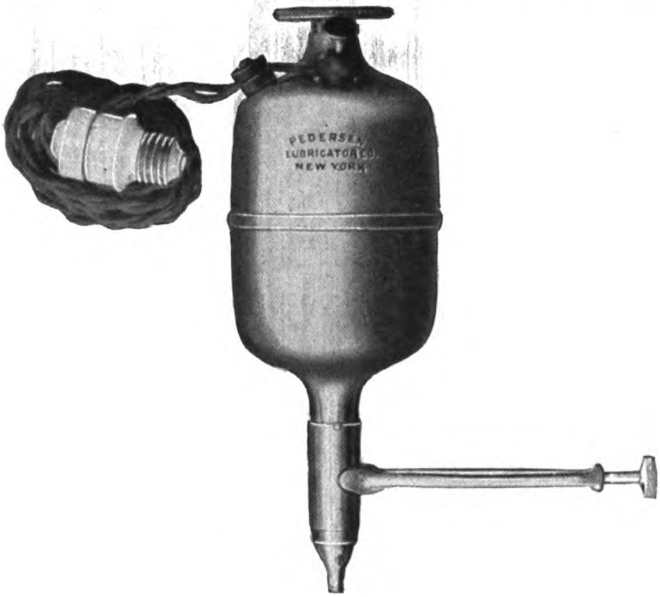

FIG. 22.—Hartley-Kenyon motor.

For those who prefer a portable engine with the instruments directly attachable to it, the Hartley-Kenyon motor is the most satisfactory (Fig. 22). The author's assemblage of electrically driven instruments can be used with it.

In addition to the type of instruments ordinarily in use in a hospital the following are required in operations for the transplantation of bone:

7. **Reamers.**—Reamers in four sizes are used to shape or enlarge the medullary canals of long bones, for the reception of transplants (Fig. 23). They are especially useful to prepare tunnels in cancellous bone for the insertion of peg transplants. A reamer propelled by the hand, can be used with much greater accuracy in many locations, than one operated by electricity.

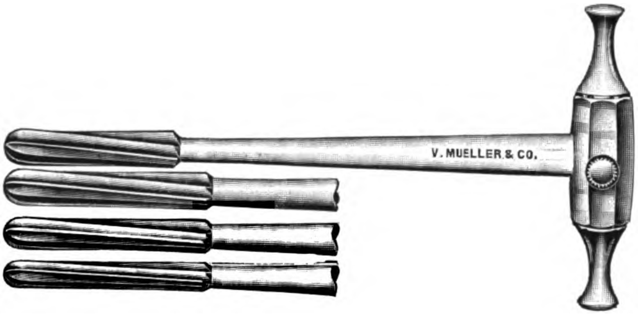

Fig. 23.—Reamers.

8. **Chisels.**—Surgical chisels are used where saws are not applicable, to shape the transplant or prepare the location for its reception. A transplant may be removed with chisels in an emergency (Fig. 24).

9. **Gouges.**—Krause's gouges. These instruments are used to make the openings in the compact bone of the femur for the reception of fibular peg transplants in repair of fractures of the neck of the femur (Fig. 25).

10. **Hammers.**—Lead hammers of considerable weight are a necessity in the use of chisels and gouges (Fig. 26).

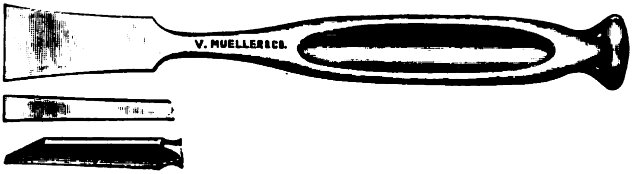

Fig. 24.—Surgical chisels.

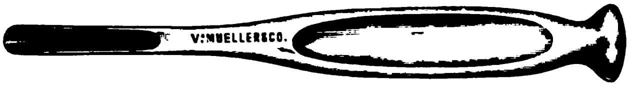

Fig. 25.—Krause's gouge.

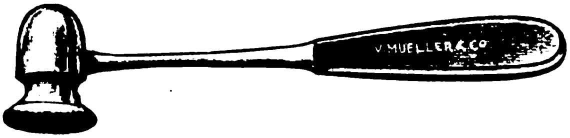

Fig. 26.—Lead hammer.

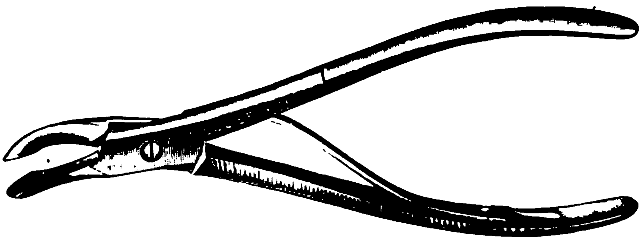

Fig. 27.—Bone rongeur forceps.

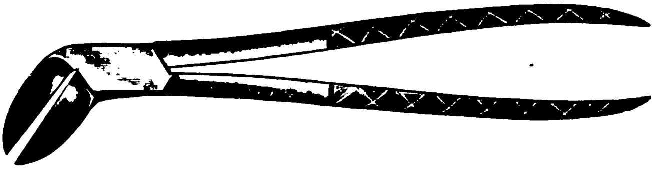

Fig. 28.—Mayo's bone-cutting forceps.

11. **Bone-cutting Forceps.**—Bone rongeur forceps (Fig. 27) and Mayo's angular, bone-cutting forceps (Fig. 28) are used in trimming and shaping bones.

12. **Periosteotomes.**—Small periosteotomes are used to elevate the periosteum at the area of transplantation and also at the source of the transplant. Periosteotomes of this shape are also used for bone elevators (Fig. 29).

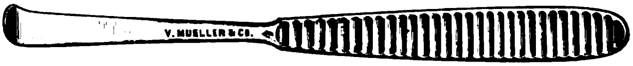
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Fig. 29.—Periosteotome.

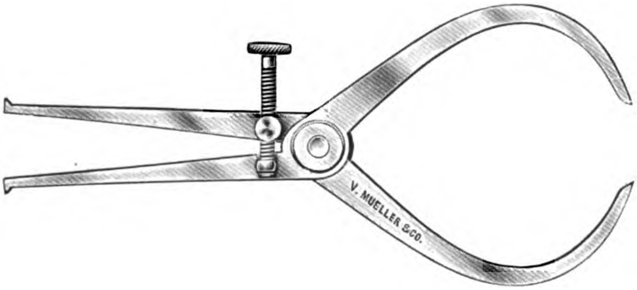
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Fig. 30.—Combination calipers.

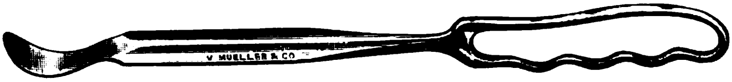

Fig. 31.—Lane's bone elevator.

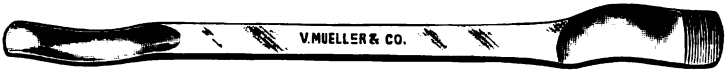
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Fig. 32.—Murphy's bone skid.

13. **Calipers.**—Combination calipers are used to simultaneously obtain the diameter of the medullary canal or other spaces and the diameters of a transplant needed to fill it (Fig. 30).

14. **Bone Levers.**—Lane's bone elevator (Fig. 31) and Murphy's bone skid (Fig. 32) are used as levers in the elevation and reduction of the fragments in autoplastic treatment of fractures.

15. **BONE-HOLDING FORCEPS.**—Lion-jawed (Fig. 33), Lane's (Fig. 34) and Lowman's (Fig. 35) forceps are used to hold the fragments in the required position during operations for autoplastic repair of fractures.

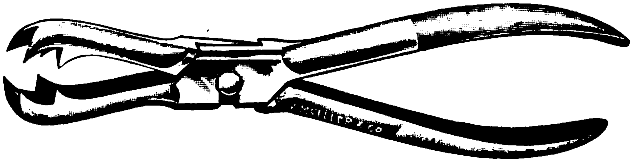


FIG. 33.—Lion-jawed forceps.

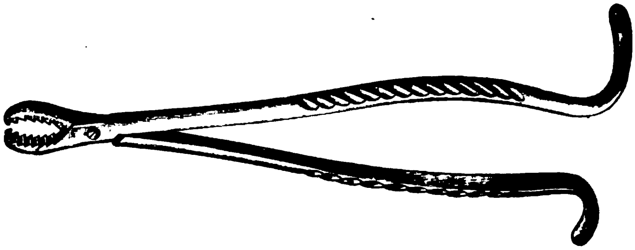


FIG. 34.—Lane's bone-holding forceps.

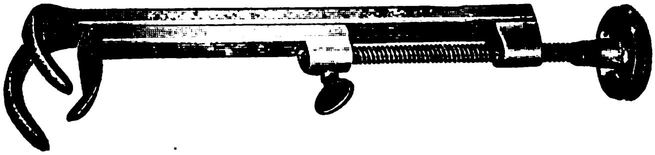


FIG. 35.—Lowman's bone-holding forceps.

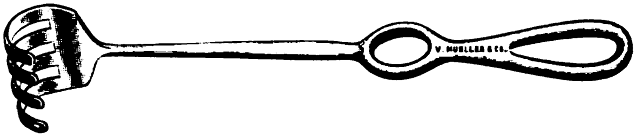


FIG. 36.—Four-pronged steel retractor.

16. **RETRACTORS.**—Israel's four-pronged steel retractors (Fig. 36) are used for bone retractors. Murphy's guide retractors (Fig. 37) are used to retract the soft parts in removing transplants from the spine of the tibia.

17. **Bone Spreader.**—A bone spreader (Fig. 38) is used to separate the fragments in the application of the medullary transplant in fractures. If the transplant becomes wedged against the opposite fragment, it can be loosened without injury and entered into the medullary canal by the use of this instrument.

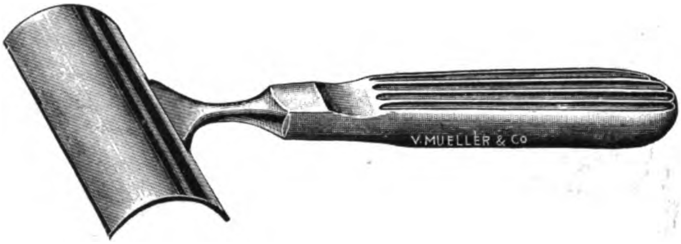


Fig. 37.—Murphy's retractor.

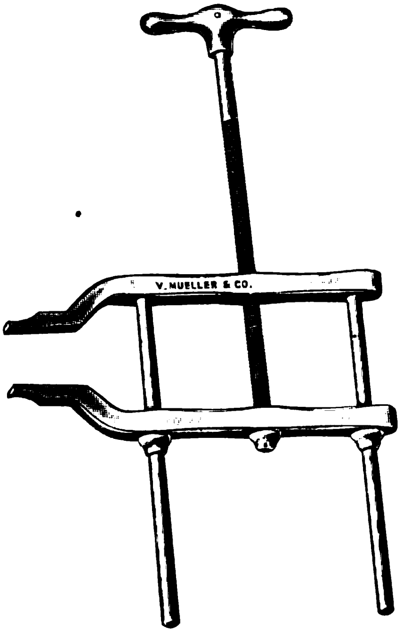


Fig. 38.—Bone spreader.

18. **Instrument Forceps.**—Heavy eight-inch forceps are used by the nurse for passing instruments and by the surgeon for handling the transplant (Fig. 39).

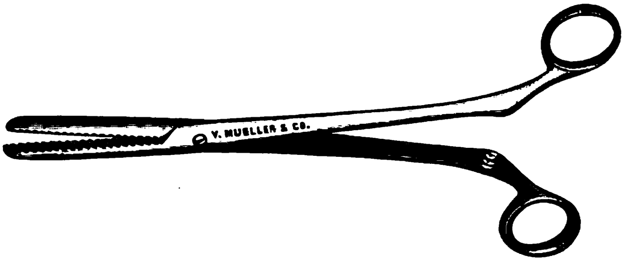


Fig. 39.—Eight-inch forceps.

19. **Tables.**—Hawley's fracture table is a great convenience in the immobilization of fractures after autoplastic repair (Fig. 40). Its use especially facilitates the application of body plaster-of-Paris casts in the immobilization of fractures of the upper part of the femur.

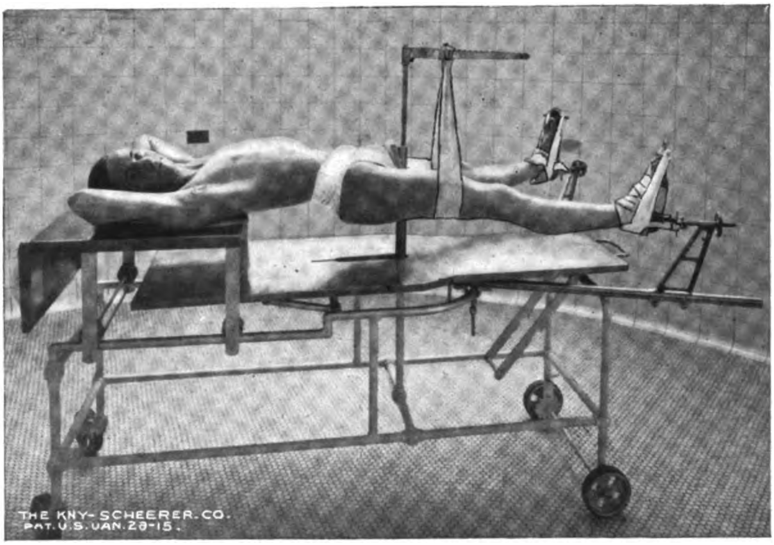


Fig. 40.—Hawley's fracture table.

THE OPERATIVE TECHNIC OF BONE TRANSPLANTATION.

The technical details essential to success in the grafting of bone are:

A. A living bone transplant from the same individual.

B. Rigid attention to the details of asepsis.

C. Preservation of the nutrition of the transplant.

D. Contact of the transplant to the recipient bone.

E. Immobilization of the transplant to its host in a neutral, muscular position.

A. A Living Bone Transplant from the Same Individual.

An autoplastic transplant, *i. e.*, derived from the same individual, when transplanted under favorable conditions, is treated kindly by the tissues, grafts to the adjacent bone and becomes a part of the skeleton.

A homoplastic transplant, *i. e.*, derived from another individual of the same species, may be treated kindly by the tissues and graft or may be resented as a foreign body, depending upon the similarity of the immunological relations.

A heteroplastic transplant, *i. e.*, derived from an animal of another species, acts as a foreign body and rarely grafts. It is absorbed, encapsulated, or gradually extruded by a proliferation of granulation tissue of the host.

A bone transplant grafts with the greatest activity when taken from the same individual, next best, when taken from the next of kin and with diminishing activity as the distance from common origin increases.

B. Asepsis.

The operative technic in autoplastic bone surgery demands the most rigorous application of the rules of asepsis as distinguished from antisepsis. The use of antiseptics destroys the living bone cells of the transplant as well as the pyogenic germ. Any substance that kills or inhibits the growth of living cells should not be used in or about the operative wound. The use of iodine, carbolic acid, bichloride of mercury and chemicals of similar action should be prohibited in the preparation of the operative field on the day of operation. Solutions of these antiseptics should not be used to rinse the hands, instruments or utensils during the operation.

Preparation.—The preliminary preparation of the operative field is done the previous day. The skin is (1) shaved; (2) scrubbed with soap and hot water; (3) washed with alcohol; (4) solution of bichloride of mercury; (5) sterile water and (6) covered with sterile gauze. At the time of operation the skin is scrubbed with sterile soap and hot water and washed clean with sterile water.

Operative asepsis is rigidly maintained. The gloved hand of the operator is not allowed to come in direct contact with the transplant or the wound, the operative manipulations being executed with instruments or with a layer of fresh sterile gauze between the hand and the wound.

Hemostasis.—Hemorrhage, when arterial, is controlled by forcipressure and absorbable ligature; when capillary, by packing the wound with dry gauze; or if persistent, by packing with gauze wet with hot normal saline solution. The tourniquet is not used because of the danger of reactionary hemorrhage with clots in the deep part of the wound, which would interfere with the vascularization of the transplant.

C. NUTRITION OF THE TRANSPLANT.

Attention to the conservation and reëstablishment of the cellular nutrition of the transplant is extremely important. The vitality of the transplant immediately after operation is sustained by:

1. Blood and fluids are retained in the transplant during the operation of transplantation, consequently the change to the new location must be made quickly before the contained fluids have desiccated or drained away. If there is temporary delay between the removal of the transplant and its application to the recipient bone, it must not be preserved in saline or other solutions, as that will attenuate and wash away the contained nutritional supply. It should be wrapped in dry sterile gauze to prevent atmospheric drying and contamination.
2. The permeation, absorption and cellular assimilation of the blood serum from the wound of the host. When the transplant is not surrounded by large blood-clots, it is bathed with free serum and for a time may maintain its vitality by direct imbibition of nourishment from that source.
3. The periosteum attached to the transplant when it is possible to retain it. The periosteum should be removed from bone to be buried in bone, but when one surface of the transplant is exposed, the periosteum should be retained on that surface and sutured to the periosteum of the host, materially aiding in the early vascular supply.
4. The early vascularization of the transplant.

D. CONTACT OF THE TRANSPLANT TO THE RECIPIENT BONE.

There must be actual bone-to-bone contact between an osteogenetic surface of the transplant and an osteogenetic surface of the host to obtain grafting between them. There must not be other tissue or extraneous material between them. Periosteum or other fibrous tissue, muscle, fat or large blood-clots between the bone surfaces prevent grafting to the extent of their interposition.

Vital injury to the superficial bone cells of the graft or of the presenting surfaces of the host prevent grafting, as frictional overheating of the sawed surfaces by an electric saw, soiling the transplant or contacting surfaces of the host with antiseptics used in the sterilization of the skin, of the operative field, of instruments or the hands of the surgeon, or contacting the graft to its host so tightly as to produce superficial pressure necrosis. By the time that the injured superficial cells have died, become absorbed and cleaned away, the underlying layer of live bone of the graft and that of the host, will have healed over and will fail to graft to the extent of the injury.

Wound Closure.—With complete hemostasis and the transplant in position, the wound is closed without drainage in layers with absorbable sutures and covered with an abundance of sterile gauze, sufficient to absorb the primary wound secretion and protect the wound without disturbance until healed.

E. IMMOBILIZATION OF THE TRANSPLANT TO ITS HOST, IN A NEUTRAL MUSCULAR POSITION.

Immobilization of the autoplastic bone graft to its host must be substantial and complete. It is accomplished by:

1. *Internal Fixation.*—The relationship between the transplant and its host often furnishes fairly substantial internal fixation, as for example, the fibular transplant in the medulla of the tibia in recent fracture, or the sawed transplant fastened by the author's method of bevelled dovetail-joints in the repair of ununited fracture of the tibia. The fixation at times may be reinforced by the use of chromic kangaroo-

tendon sutures, passed around the transplant and through holes drilled in the host.

Except as a last resort only when every other means has failed, should the transplant be secured to its host by wire, nails or other metal fastenings, as the presence of any foreign body depresses the tissues and tends to inhibit the process of grafting.

2. *Position of the Host.*—The position of the host as exampled by an extremity, should be a position of normal alignment and rotation, in which there is complete relaxation of the muscles acting upon the area of the autoplasty. Any neglect of neutralizing the muscular action by position will allow spasmodic movement between the transplant and its host. Irregular movement or leverage will either dislodge the transplant, shear it across or cause it to cut through its host, depending upon which direction furnishes the least resistance.

3. *External Solidifying Dressings.*—External immobilization is best accomplished by plaster of Paris over the sterile dressings. A close-fitting plaster cast, appropriate to the location, is applied including one or more joints on either side of the autoplastic repair. The immobilization should be constantly maintained until stable grafting has occurred. If attention to the wound becomes necessary, an opening can be cut in the cast of sufficient size to allow redressing of the wound, without disturbing the immobilization or weakening the cast.

THE TRANSPLANT.

REQUIREMENTS OF THE TRANSPLANT.

The transplant is obtained from the same individual and should be as near an elementary bone unit as the conditions of transplantation and the processes of grafting will permit.

An ideal transplant should contain cortical bone, endosteum and periosteum, each layer being apposed to the corresponding layer of the host, but this ideal transplant must be modified by the location of transplantation and conditions of grafting. A transplant that is buried in bone so that no part of it is exposed at the surface, must have the periosteum removed, as it acts as a limiting membrane and prevents grafting to the extent of its interposition.

The cortical bone is the essential element of the transplant because of (*a*) its resistance to change of material form, by which it gives support to its host; (*b*) its small normal vascular supply, which allows it to retain its vitality for a time after transplantation, sustained by a minimum amount of nutrition; (*c*) its active osteogenetic properties, which cause it to graft with rapidity and firmness.

The addition of the periosteum and endosteum is of value in conserving the vascular supply to the cortical bone immediately after transplantation and in aiding its early revascularization.

Periosteum must not be interposed between surfaces of bone which are expected to graft. The transplant should be composed of the smallest amount of bone that will fulfil the indications requiring the transplantation, under good conditions, in the shortest time. Small fragments retain their vitality and graft better and quicker than large fragments.

SOURCE OF THE TRANSPLANT.

The locations from which the transplant may be obtained are:

1. THE SAME BONE IN THE IMMEDIATE VICINITY OF THE REPAIR.—Sometimes the ingenuity of the surgeon will provide a transplant from the same bone in the neighborhood of the repair without invaliding

another extremity. This is done in the inlay transplant in recent fractures, and sometimes in the cortical bone graft in ununited fractures.

To obtain the transplant, it is outlined by means of the parallel saws, then removed with a single saw to make the proper bevels, and finally the ends are cut across with a chisel or small saw.

A fragment of bone in a recent fracture, separated from its normal connections and lying loose among the blood-clots for some time, is devitalized and should not be used as a transplant with the expectation that it will live and graft to the surrounding bone.

2. THE SPINE OF THE TIBIA.—This location furnishes thick compact bone of a most substantial and desirable character. It has great osteogenetic activity and grafts quickly and solidly. The dense bone of the crest of the tibia has only a small blood supply under normal conditions and environments, and its nutritional requirements when transplanted are less than that of more vascular bone.

Bone from this location is available for transplantation in a large variety of cases where solid compact bone is needed that will graft quickly and absorb slowly. It supplies the best material in most cases for medullary and peg transplants in recent fractures, grafts in ununited fractures, long transplants for closing certain defects of long bones and splint material in Albee's operation for tuberculous spondylitis.

To obtain the transplant, its measurements are secured and its shape outlined on the bone. It is removed by a motor saw with a single blade, cutting in each direction until the lines intersect. The ends are severed with the same saw cutting on a bevel toward the transplant (Fig. 41).

In the absence of an electric motor outfit, the transplant may be removed with a hammer and chisel.

Accidental fracture of the tibia may occur when bone for transplantation is removed by this method, unless attention is given to the support of the tibia while the chisel is being used.[4]

3. THE INTERNAL SURFACE OF THE TIBIA.—The internal surface furnishes a flat area of bone for transplantation of a more vascular type than the crest. It is available for a cortical transplant in ununited fracture, closing defects in the skull, in spina bifida, making irregular-shaped transplants in Albee's operation for tuberculous spondylitis and in any other location in which a flat, wide segment of bone is required for transplantation.

To remove the transplant, it is outlined on the bone by measurement or pattern. When its sides are to be parallel and at right angles to its surface, they are cut with parallel saws, but if the sides are bevelled, they are outlined with parallel saws and cut on bevels with a single saw. The ends are cut across with a saw small enough in diameter so that it will not cut into the tibia beyond the transplant. If the transplant is to be irregular in shape, it is cut by saws and chisels along the lines of the irregularity.

4. THE FIBULA.—A segment of fibula furnishes an ideal bone unit

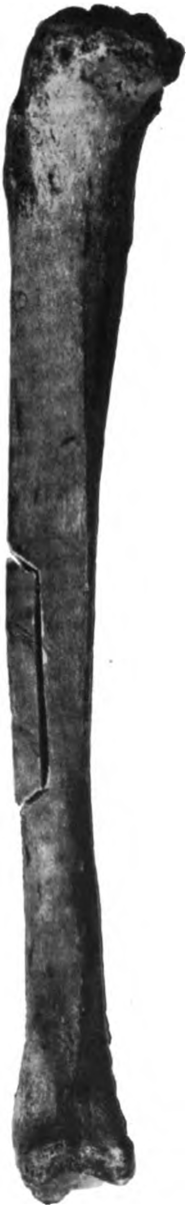


FIG. 41.—Specimen showing manner of removal of a transplant from the spine of the tibia.

for transplantation when its shape and size are applicable. The transplant includes a circle of cortical bone covered with periosteum and lined with endosteum filled with undisturbed marrow, a most favorable combination for maintaining its vitality.

It furnishes the best material for repair of recent fracture or ununited fracture of the neck of the femur and for recent fracture of the tibia in which the medullary cavity is large enough to receive the fibular transplant.

Because the fibula is a bone unit of large size and length that can be easily removed from its normal location without material loss of the appearance, strength or function of the leg, it is the best material for the repair of large defects in long bones produced by traumatism, acute osteomyelitis, tuberculosis, cystic or malignant disease.

The fibular transplant is removed with Gigli or chain saws. The lower section of the bone should not be less than 5 cm. from the external malleolus to prevent disturbance of the function of the ankle-joint. Usually the segment is resected from the middle or lower part of the diaphysis. If the upper part of the bone is removed, the peroneal nerve must be avoided.

Transplantation to replace the entire diaphysis of a long bone may require the removal of the entire fibula except the external malleolus. The upper end may be required to secure a cartilaginous surface for use in a joint where the epiphysis of the recipient bone has been destroyed.

5. THE POSTERIOR BORDER OF THE ULNA.—The subcutaneous part of the posterior border of the ulna furnishes an area of compact bone suitable for transplantation. It is available when a small transplant is needed for one of the bones of the same forearm,

when objection is made to invaliding another extremity. The transplant is removed in the same manner as from the spine of the tibia.

6. The Scapula.—The scapula furnishes an area of thin, flat, fairly compact bone, with both surfaces covered by periosteum. It is especially suitable for transplantation into cranial defects where a periosteal surface applied next to the brain or its membranes acts as a limiting layer to the formation of new bone, preventing pressure and irritation of the brain substance. The posterior border may be utilized for remodelling the bridge of the nose for congenital deficiency or acquired deformity. It furnishes a transplant of the proper length, size and curve, covered on three sides by periosteum, which as a limiting tissue prevents renewed deformity by overgrowth of the transplanted bone.

7. The Rib.—Segments of ribs are useful for transplantation when the shape and cancellous character of the bone are not objectionable, as for filling defects of bone, supporting overstretched soft tissues, etc.

HEMORRHAGE AT THE DEFECT CAUSED BY REMOVAL OF THE TRANSPLANT.

The nutrient artery of a bone should not be destroyed in the removal of bone for transplantation, because its destruction interferes with the nutrition of the bone and the subsequent regeneration at the defect caused by the removal of the transplant. If the artery or one of its branches is opened, producing troublesome hemorrhage, or if there is free medullary oozing, hemostasis may be produced by the application of a graft of adipose tissue to the bleeding area.

FRACTURE OF THE TIBIA FOLLOWING REMOVAL OF BONE FOR TRANSPLANTATION.

The possibility of postoperative fracture of the tibia must not be overlooked or minimized. During removal of the transplant it must be remembered that the tibia is being robbed of functional bone, that the amount of bone removed must be limited to the necessities of the transplantation and that the manner of removal must conserve the strength of the mutilated tibia (Fig. 42).

The removal of a segment of the crest of the tibia opening into the medullary canal weakens it out of all proportion to the amount of bone excised, probably because it interferes with the tubular relations of the cortical bone. By overcutting the tibia at the ends of the transplant the bone is temporarily weakened to the extent of the overcut defect. By cutting the ends of the transplant at an acute angle or even a right angle, a weak place is left in the tibia at which a fracture may originate (Fig. 43).

Morris reported a case at the New York Surgical Society[5] in which a transplantation for a cranial defect had been done. A piece of bone one and one-fourth inches in length and one and one-eighth inches in width was removed from the internal surface of the tibia. Thirty days after operation the patient returned to the hospital with a transverse fracture of the tibia at the site from which the transplant had been removed. Morris also stated that he had lately heard of four similar cases.

A case of fracture of the tibia following transplantation into an ununited fracture recently occurred in the service of Dr. F. G. Dyas at Cook County Hospital. A transplant five inches in length and one-half inch in width and thickness was removed from the spine of the tibia. Eighteen days after operation the patient fell from a wheel-chair and fractured the tibia from which bone for transplantation had been removed.[6]

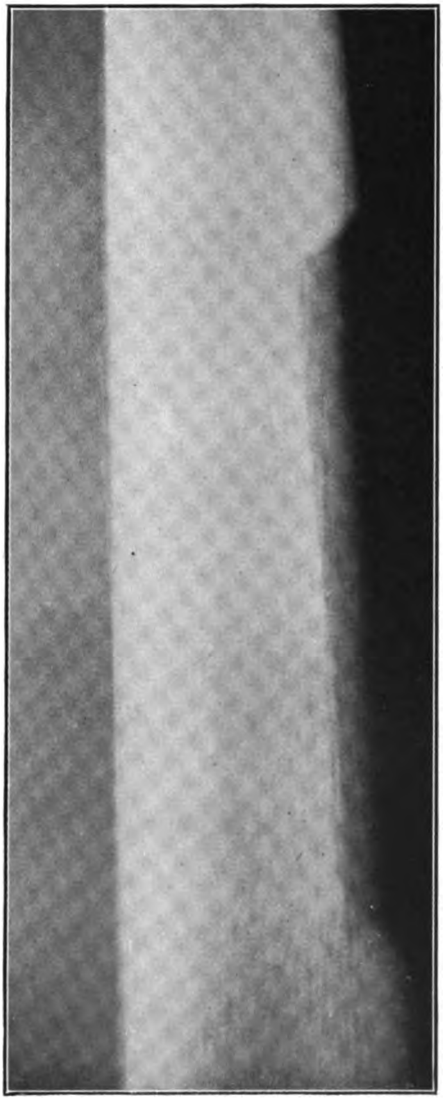


FIG. 42

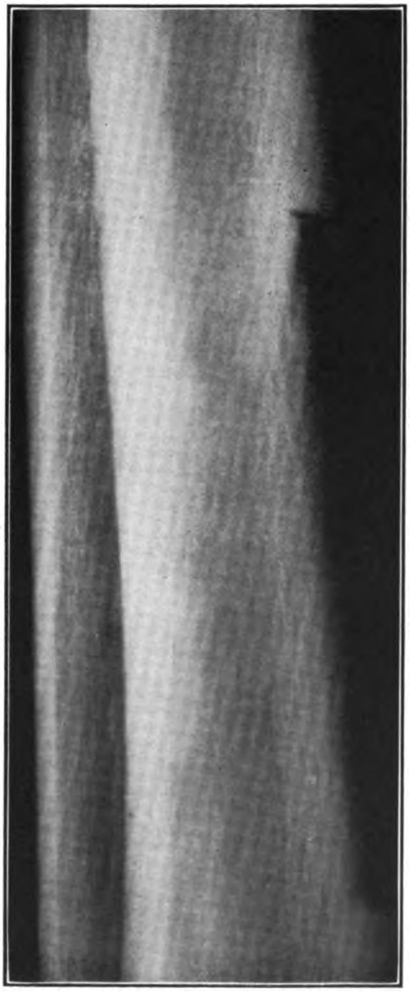


FIG. 43

FIG. 42.—Röntgenogram, showing immediate defect in spine of tibia after conservative removal of a transplant.

FIG. 43.—Röntgenogram, showing immediate defect with an acute angle after removal of a transplant from the spine of the tibia.

A röntgenogram of the leg (Fig. 44) shows a transverse fracture of the tibia. The line of fracture extended

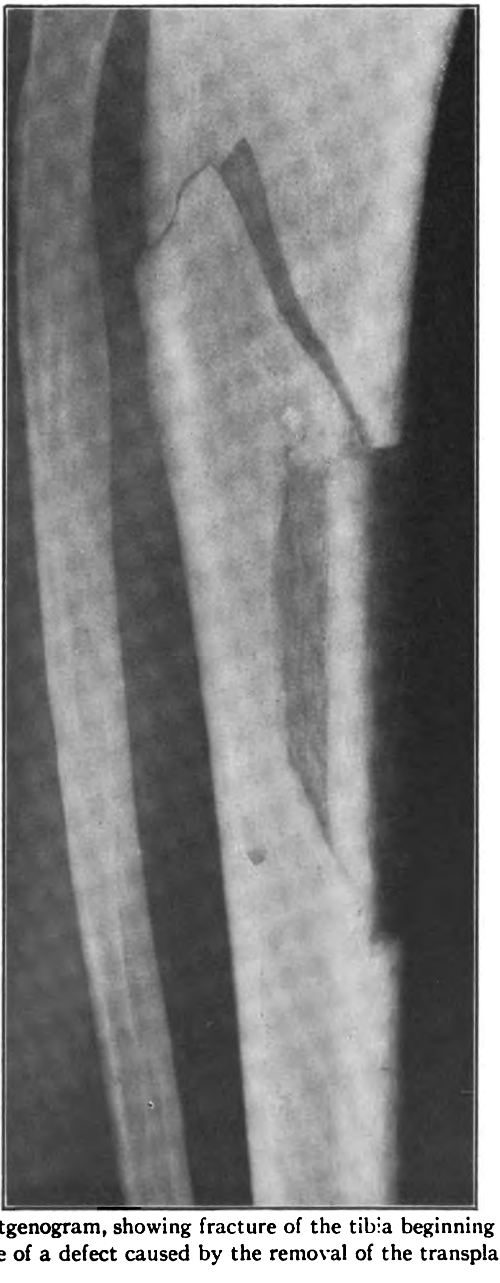


FIG. 44.—Röntgenogram, showing fracture of the tibia beginning at the upper angle of a defect caused by the removal of the transplant.

from the upper angle of the defect caused by the removal of the transplant.

Fracture of the tibia following removal of a transplant for a cranial defect occurred in one of Rhodes's cases.[7] The transplant was taken from the flat surface of the tibia and was about two inches long by one inch broad and practically the entire thickness of the bone. Twenty-seven days after operation the patient fell in the street during a convulsion and sustained a fracture of both bones of his leg. The line of fracture extended from the upper end of the defect in the tibia.

Solid bony union followed immobilization of the fracture in each case in the usual time.

Röntgenograms of six cases of fracture of the tibia following the removal of bone for transplantation were privately shown during a recent meeting of the American Röntgen Ray Society.

The tibia should be protected from fracture by a plaster cast during the period of regeneration at the defect caused by removal of bone for transplantation.

REGENERATION OF BONE AT THE DEFECT CAUSED BY THE REMOVAL OF THE TRANSPLANT.

When a graft is removed for purposes of transplantation it is replaced by a deposit of new bone, with a facility depending upon the size of the defect, the age and physical condition of the patient. Responding to functional demands for strength, bone is regenerated in the defect and existing bone hypertrophies until the equilibrium between function and strength has been reëstablished. Prompt regeneration of bone in the defect in the tibia from which transplants had been removed in the author's cases was shown by serial röntgenograms.

Regeneration after removal of a whole segment of a bone for transplantation is more uncertain. Peronectomy is done with little consideration of any regeneration which may follow. When the epiphyses are undisturbed and the periosteum remains, there may be regeneration of the entire segment of the fibula. This is illustrated in Case No. 17 (Figs. 109 and 112) in which there was complete bony replacement of the segment in seven months. On the other hand, age and debility may entirely prevent bone regeneration, as is illustrated by Case No. 22 (Fig. 127) and Case No. 24 (Fig. 135), where there was no replacement of definite bone in four months.

That the whole diaphysis of a long bone may be regenerated under certain favorable conditions is well shown in the history of the following personal case.

CASE NO. 1.—Osteomyelitis with removal of the entire diaphysis of the tibia with complete regeneration.—P. W.; American; school-girl; aged nine years; entered the West Side Hospital May 23, 1907, with acute infectious osteomyelitis of the tibia, with complete necrosis of the diaphysis. The sequestrum, consisting of the entire shaft of the tibia, was removed and the suppurating cavity thoroughly curetted, swabbed with 95 per cent. carbolic acid and packed with gauze. The epiphyses were not disturbed. The patient left the hospital in one week with the leg supported by a posterior molded splint. The wound suppurated for six months, at the end of which she was about on crutches, and in one year was walking without support. Examination seven years later showed a leg of normal size and length with perfect function. A röntgenogram taken at that time shows very complete regeneration of the diaphysis of the tibia (Fig. 45).

The results in the following case are in sharp contradistinction.

CASE NO. 2.—Amputation for pathological fracture of the femur.—E. C.; American; housewife; aged

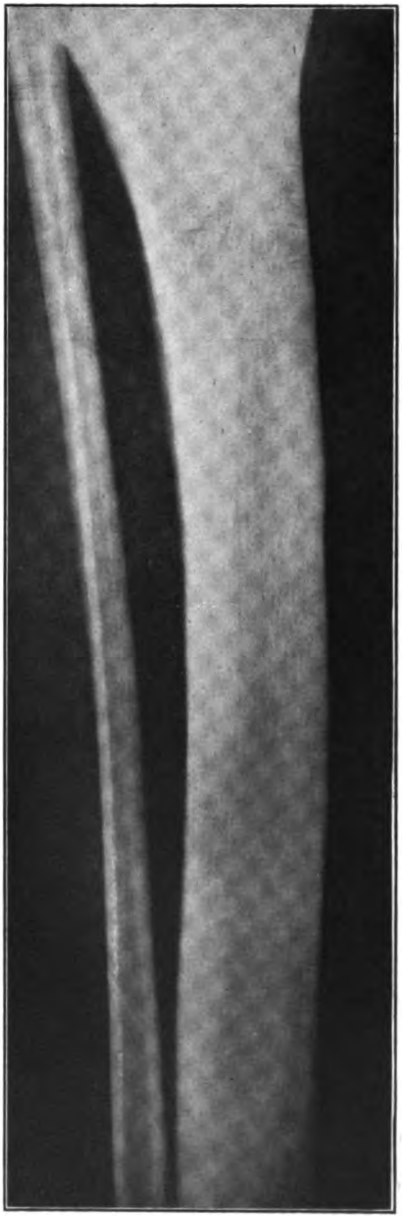


FIG. 45.—Case No. 1. Röntgenogram, showing regeneration of the diaphysis of the tibia.

thirty-four years; entered the University Hospital with a pathological fracture of the left femur of three

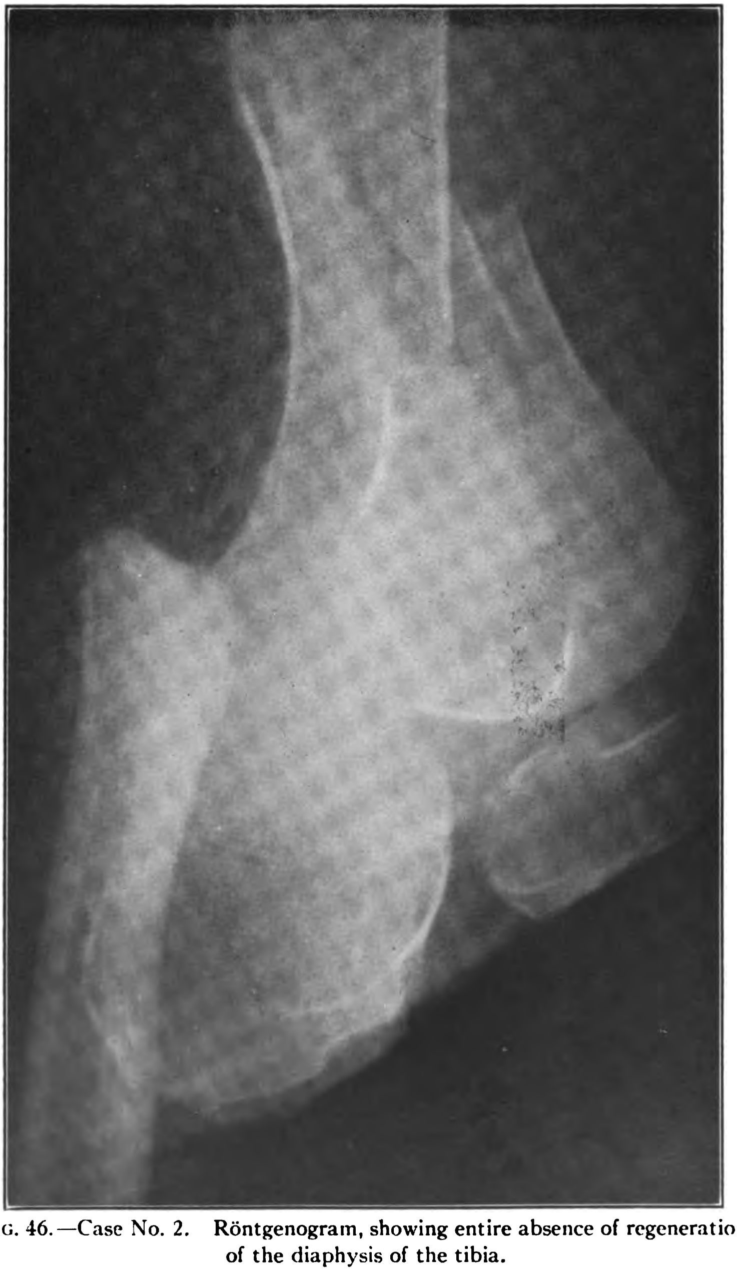


Fig. 46.—Case No. 2. Röntgenogram, showing entire absence of regeneration of the diaphysis of the tibia.

weeks' standing. At seventeen years of age the patient jumped from the third story of a burning building, receiving severe injuries to both legs. These injuries were followed by osteomyelitis of the left tibia, which required complete removal of its diaphysis. The patient used crutches until the occurrence of the fracture of the femur. Röntgenological examination showed absence of the diaphysis of the tibia. The tibial epiphyses were present. The fibula was much hypertrophied and its upper end was dislocated (Fig. 46). Dissection of the amputated specimen showed entire absence of bony regeneration.

In general terms, it is probable in the event of failure of regeneration of bone, when a segment of the whole thickness has been removed for transplantation, as in the fibula, that a compensatory hypertrophy will occur in the adjoining bone.

INFECTION OF THE TRANSPLANT.

The grafting of the transplant to its host occurs in an ideal manner, similar to primary union of the soft parts, only when the surrounding wound remains free from infection. The wound of transplantation is no more likely to become infected than any other wound of bone with similar surroundings. The transplant consists of living tissue with germ-resisting properties which aid in the prevention of infection of the wound. With reasonable care the wound may be expected to remain clean, to heal by primary union and the transplant to graft to its host by direct adhesion. When the transplant is infected, it becomes a sequestrum and is extruded only in a small proportion of cases.

In Trout's experimental work on Belgian hares, a series of forty-four transplantations in the presence of infection of the wound showed the extrusion of five transplants as sequestra, while thirty-nine grafted and remained in position until the animals were killed, four months after transplantation.[8]

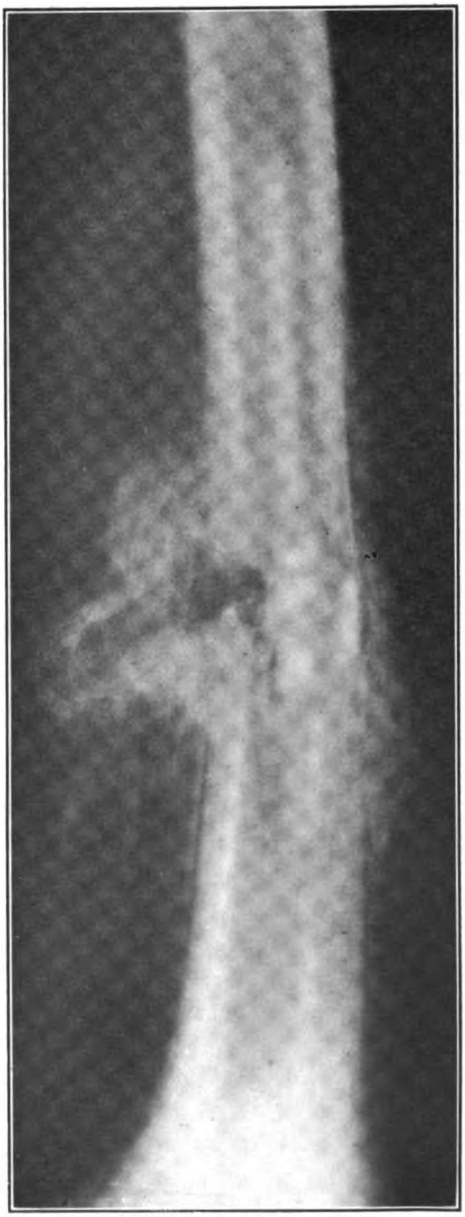
It is apparent from the results of experimental work and from clinical data, that when the transplant becomes infected, it reacts to the infection very much the same as bone in its original location, that the part of the transplant directly exposed to the infection is more or less destroyed or eroded by the infective process, and that the part protected from direct attack lives, grafts and reacts to the infection as an integral part of the host bone.

The breaking down of bone at the site of transplantation by the processes of infection liberates bone cells and as suppuration subsides, excessive callus forms throughout the area of infection.

The history of the following case in the service of Dr. Kellogg Speed illustrates the resistance of the transplant to infection and the excessive callus on recovery.

Case No. 3.—Fracture of humerus.—H. B.; German-American; teamster; aged twenty-one years; was admitted to Cook County Hospital April 10, 1914. His left arm had been broken beneath the wheel of a moving wagon. Autoplastic repair of the fracture was done. A tibial transplant 8 cm. long and 1 cm. thick was placed in the medullary canal of the humerus across the fracture, the wound dressed and immobilized by an anterior molded splint. The wound became infected, discharged pus for three weeks, after which it healed and the fracture united with abundant palpable callus.

Röntgenograms taken fourteen weeks after operation show the transplant alive and grafted into each fragment. It has been cut across by suppurative disintegration at a line corresponding to the fracture, where



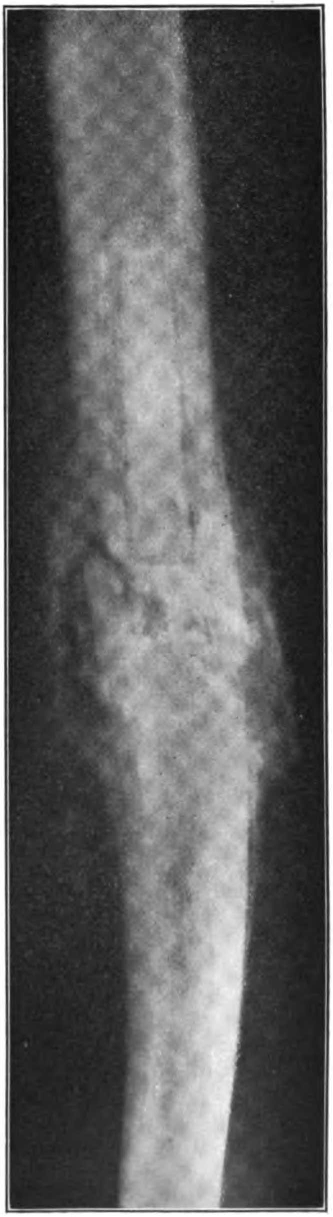


FIG. 47 FIG. 48

FIG. 47.—Case No. 3. Röntgenogram of autoplastic repair of fracture of the humerus, fourteen weeks after operation, showing result of infection. Lateral view.

FIG. 48.—Case No 3. Röntgenogram of autoplastic repair of fracture of the humerus, fourteen weeks after operation, showing result of infection. Anteroposterior view.

it was exposed to the infection. The fracture is surrounded by excessive callus (Figs. 47 and 48).

While a transplant does not necessarily die in the presence of infection, the possibility of the continuance of suppuration and its sequestration is so great that transplantation into an infected area is contra-indicated, unless there is an unusual demand for immediate transplantation which overrules the contra-indication.

Healthy functional bone should not be sacrificed for transplantation into an infected area except under the most urgent demands for immediate support, regardless of the ultimate fate of the transplant.

CHAPTER VI.

AUTOPLASTIC REPAIR OF RECENT FRACTURES.

DESCRIPTION OF METHODS.

THE most promising field for autoplastic bone surgery is in the repair of a certain class of recent simple fractures of long bones which are difficult of reduction and immobilization. The grafting of fresh live bone from the same individual, across the line of fracture, furnishes a method of alignment and fixation by a living, germ-resisting, osteogenetic structure, which is treated kindly by the tissues and which heals in as an integral part of the body.

Transplantation of bone acts in sharp contrast to the use of metal plates, screws and nails, which are foreign bodies, always producing a certain amount of pressure necrosis, absorption and disintegration of tissue. A foreign body depresses the local resistance of the tissues. The lowering of vitality always favors infection. A foreign body is resented by the tissues and at the best is only tolerated. A foreign body invites infection. Transplanted living bone resists infection.

There are three methods in use for the autoplastic repair of recent simple fractures, depending upon the location and conditions of the fracture.

1. MEDULLARY TRANSPLANT.—When a simple fracture of a long bone is immobilized by external splints in such a position that its medullary canal is patulous, an internal callus is rapidly produced across the line of fracture as a part of the process of support and repair of the fracture. The internal callus ossifies

and becomes a medullary plug of bone, aiding in the immobilization and giving support to the fragments during the formation and ossification of the permanent callus.

In the physiological process of the healing of bone after fracture, the internal callus is a natural medullary bone splint, remaining as long as its support is required by the injured bone, after which the unnecessary part is gradually absorbed as the permanent callus becomes effective.

The medullary transplant is applicable to fractures of the shafts of long bones in which there is a medullary canal on either side of the fracture for a sufficient distance to allow it to be received into a natural bone cavity, and in which the physical surroundings of the fracture are such that it can be placed into the medullary canal without material injury to other structures.[9]

A medullary transplant is obtained, usually, from the tibia or fibula, of a sufficient length to make the reduction stable. Its thickness should be sufficient to make bony contact with at least a part of the circumference of the interior of the shaft. The transplant after introduction should fit loosely enough to facilitate its nutritive supply and avoid pressure necrosis of its surface. The periosteum should be removed from the transplant, as it is to be buried in bone. The presence of periosteum would prevent bone-to-bone contact, necessary for the grafting process.

A fragment loosened by the injury at the point of fracture and lying for some time loose in the tissues, torn from the periosteum, is dead bone and is not proper material for a transplant. It must be living bone and placed in its new environment quickly before its supply of nutrition has been exhausted or destroyed.

In the application of the medullary transplant, incision is made over the fracture. The ends of the fragments are exposed and the blood-clots and other products of the traumatism removed from around the fracture with as little disturbance to the periosteum as possible. The medullary canal of each fragment is cleared, with a bone curette, of that part of its marrow which has been disturbed by traumatism, hemorrhage or inflammation.

After measurement of the medullary canal a transplant of proper proportions is obtained and fitted to one fragment, so that it will slip into the canal smoothly. This usually is done by scraping out the canal with a sharp bone curette or with a reamer of the same size as the transplant.

After fitting the transplant in this manner, usually to the proximal fragment for convenience of later manipulation, the other fragment is brought into the field of operation, and the transplant fitted and driven one-half its length into the medullary canal. The distal part of the extremity, with the transplant projecting from its fragment, is placed at an angle to the axis of the proximal part of the extremity. The lower fragment is then sharply retracted and manipulated so as to enter the transplant into the medullary canal of the upper fragment, which is then swung into proper alignment with the remainder of the extremity (Fig. 49). The muscles immediately contract and bring the fragments together.

Alignment of the fragments is the primary function of the transplant. Grafting of the transplant to the fragments is secondary, but very desirable.

The transplant maintains the reduction, lives and grafts to the compact bone of the fragments under the following conditions:

1. An aseptic operative wound.

2. A live transplant from the same individual, without periosteum. Periosteum is a fibrous tissue

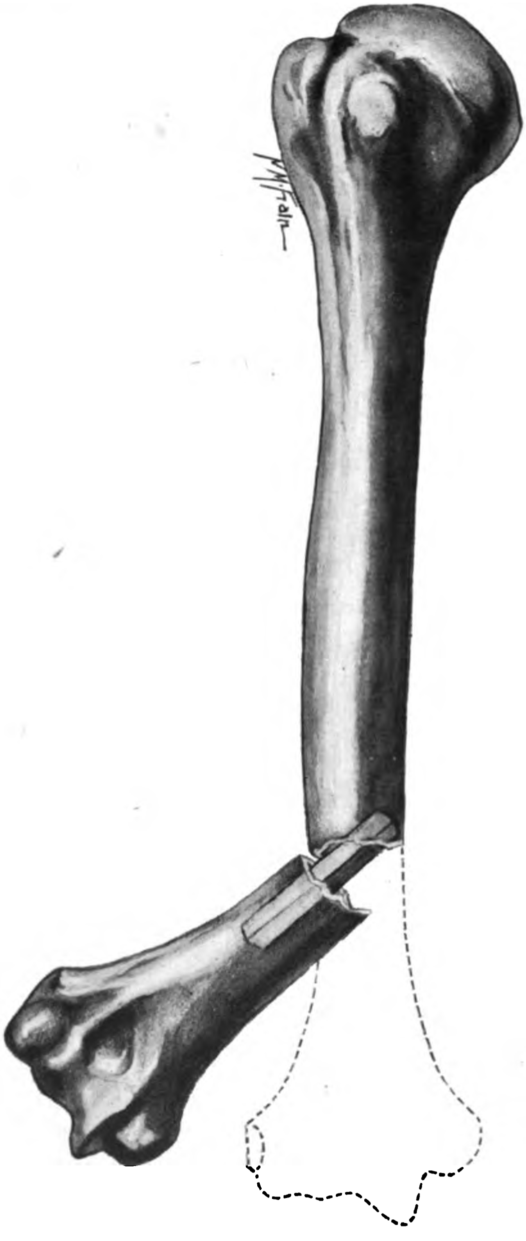


FIG. 49.—Introduction of the medullary transplant in recent fracture of the humerus.

and when retained on bone, buried in bone, prevents grafting to the extent of the interposition.

3. Actual contact between the transplant and the compact bone of each fragment.

4. External immobilization of the fragments, so that there is no movement between the transplant and its host.

Under these favorable conditions the transplant becomes a living integral portion of the repaired bone, taking its part in the functional support of the extremity and maintaining for the time its shape and size, later to be modified, like any other part of the skeleton, by the conditions and functional demands put upon it. It remains as long as its support is required and then the superfluous part is gradually absorbed and the medullary canal reëstablished.

If the transplant is not in bony contact, fibrous union between it and the interior of the fractured bone can be expected, with absorption of the transplant, after union of the fracture.

If the transplant dies because of scanty nutrition, it will be encapsuled and absorbed long after union of the fracture.

2. Peg Transplant.—The ends of long bones are composed of spongy cancellous bone, covered by a thin layer of compact bone, without a definite medullary canal. The peg transplant has its field of usefulness in fractures of the ends of long bones where there is no medullary canal.[10]

The area of fracture is exposed in the same manner and with the same technic as for the application of the medullary transplant. A plan is adopted for the application of a transplant which will, in the individual case, best retain the fragments in reduction. The space that the transplant must bridge is measured and its necessary size estimated. The transplant is obtained, of the size and length required, without periosteum, from the tibia, fibula or ulna, as the conditions demand. If it is a sawed transplant, it should be slightly tapering from end to end, so as to wedge when driven into place. In the application of the transplant, the fragments are reduced and a canal is cut, with a gouge or reamer, through the bone across the line of fracture in a direction that will give the best fixation. Points of contact with compact bone are secured wherever possible for leverage and centres of grafting. The openings through the compact bone must be fitted to the transplant closely, so that it will bind and retain the fragments in reduction. The hole must not be too small or the fragment will be split when the transplant is driven into it. When in position, the transplant will be in contact with both the compact bone of the cortex and the cancellous bone inside, furnishing temporary support for the fracture and favorable conditions for grafting (Fig. 77).

The peg transplant maintains the reduction, lives and grafts to the surrounding bone under the same conditions required by the medullary transplant. The ends of the transplant graft directly to the compact cortical bone at the points of contact. That part of the transplant which is buried in cancellous bone, stimulates the production of osteoblasts and growth of new bone, which spreads from it and infiltrates the cancellous bone until they merge into a continuous bony mass across the line of fracture. This new bone increases in solidity and strength according to the functional demands put upon it, taking its part in the support of the extremity. It is later modified and absorbed as the necessity of support lessens.

3. INLAY TRANSPLANT.—The inlay transplant, "the inlay bone graft," described by Albee,[11] is obtained

from the fractured bone by taking a segment from each fragment of equal width, but of unequal length and reversing the position of the long segment in the gutter so that it will span the line of fracture (Fig. 50). The application of the inlay transplant requires that the fracture shall be in a long bone, with an even, fairly straight, flat surface, from 18 to 20 cm. in length, two-thirds of which must be on one side of the line of fracture and one-third on the other.

A very long incision is needed to expose the fracture and the area of transplantation. A segment of bone for an inlay transplant is marked out with the parallel motor saws on one fragment, long enough to bridge the fracture and extend 6 or 7 cm. into the solid part of each fragment when the inlay transplant is in position in its gutter across the fracture. The segment of bone is removed by a single motor saw, cutting on a bevel toward and into the medullary canal. The end is cut with a small single motor saw or chisel. Another segment of bone one-half of the length of the inlay transplant, of the same width and bevel, is removed from the opposite fragment in such a location that

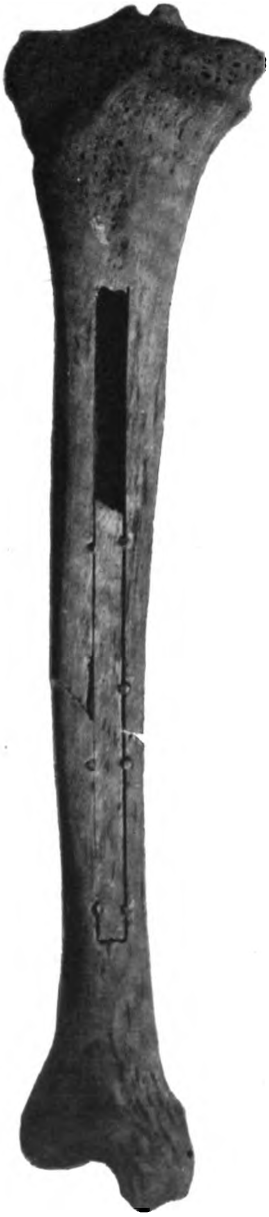


FIG. 50.—Prepared specimen, showing the inlay transplant.

the gutters will be in line when the fracture is reduced. The transplant is reversed in position, so that it bridges the fracture, one-half of its length resting in the gutter in each fragment. When it is pushed into the gutter, the bevels bind and prevent it from dropping into the medullary canal. With the object of securing the inlay transplant, Albee splits the short segment into pieces and shapes them into small pegs with an electric dowelling instrument and uses them for binding the transplant into the gutter. The bone destroyed by the saw is sufficient to allow the transplant to sink below the edges of the gutter, furnishing a margin into which holes are drilled obliquely outward to receive the small pegs.

The periosteum is protected during the operation so that all parts of the transplant are eventually covered by it. At the beginning the periosteum is stripped from the small segment which is to be cut up for pegs. Upon removal of the long segment, which is to be the inlay transplant, the distal half of the periosteum is stripped back and the other half is allowed to remain attached. By this arrangement the periosteum may be sutured so that it completely covers the transplant.

The inlay transplant lives, grafts to the adjacent bone and becomes a permanent integral part of it under the same conditions required for grafting by a medullary transplant.

The inlay transplant has the disadvantage of limited application. It is limited to fractures of long bones, without comminution, in a locality where the bone is flat and straight for a distance, on one side of the line of fracture, sufficient to make a gutter for one-half of the transplant and on the other side, to obtain the transplant. It is also limited to fractures of one or two parallel bones where the supporting bone is still intact, *e. g.*, fractures of the shaft of the tibia where the fibula is not broken, and fractures of the shaft of either the radius or ulna.

The inlay transplant does not furnish sufficient strength of fixation to be reliable in fractures of unsupported single long bones. The manipulations during immobilization, or the leverage of the extremity distal to the fracture, is liable to displace the transplant, even when supported by a well-fitting plaster cast.

Bone wedging, as suggested by Gallie,[12] is a modification of the autoplastic inlay transplant. The operation consists in cutting a truncated wedge-shaped piece of cortical bone from each fragment, one twice the length of the other and slightly wider. The larger piece is wedged across the line of fracture and the smaller piece is placed in the space from which the larger was removed.

SPECIAL RECENT SIMPLE FRACTURES.

Fractures of the Humerus.

Special Anatomy.—A median longitudinal section through the humerus shows that the shaft is a cylinder of compact bone with a central medullary canal, nearly circular in outline, smaller in the middle, expanded at either end and filled with marrow. The interior of the upper end of the humerus is composed of a mass of soft, cancellous bone, covered by the articular cartilage and by a thin layer of compact bone continuous with the compact bone of the shaft. The medullary canal ceases as the shaft expands into the upper extremity of the humerus and becomes obliterated by the cancellous bone (Fig. 51). At the lower extremity the compact bone of the shaft becomes expanded and flattened into the condyles of the humerus. The medullary canal ceases above the condyles and its space becomes obliterated by cancellous bone of a firmer character than that at the upper extremity of the bone (Fig. 52).

There is a definite medullary canal in the shaft of the humerus which can be utilized to receive a medullary transplant, in the autoplastic repair of fractures. In fractures of the upper or lower extremity of the humerus there is no natural canal that can be utilized for bone repair. It is necessary to cut a canal of the correct size, in the proper direction across the line of fracture, through the cancellous bone to receive the autoplastic peg transplant. The cancellous bone, fitting snugly to the transplant, with its free circulation, furnishes it temporary nutrition until circulation is established.

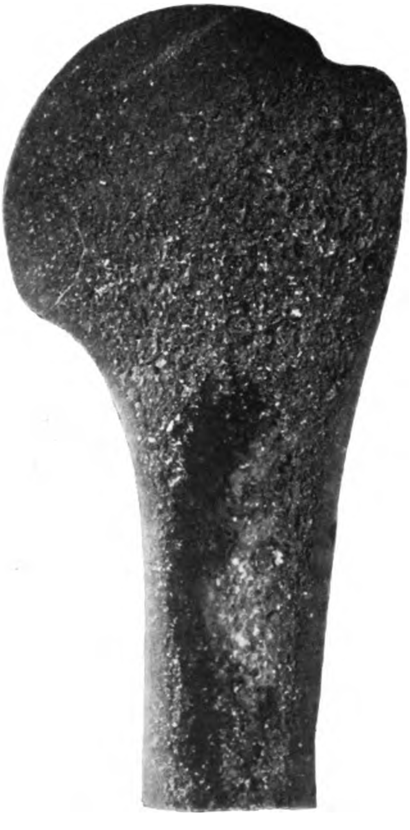


FIG. 51.—Section through the head of the humerus.

1. FRACTURE OF THE ANATOMICAL NECK AND FRACTURE THROUGH THE UPPER EXPANDED END OF THE HUMERUS.—Fractures in this location may consist of a break following the line of the anatomical neck of the humerus with the small fragment intracapsular,

or more commonly the line of fracture follows partly along the groove of the anatomical neck and then passes through the greater tuberosity, leaving the upper fragment partly intracapsular and partly extracapsular. There may be severe comminution with or without impaction of the fragments. The upper fragment may be displaced, rotated or entirely separated from the lower fragment, depending upon the kind and severity of the injury received.

The prognosis in these cases, when treated expectantly, is poor, so far as restoration of the function of the shoulder is concerned. The imperfect reduction, the excessive callous formation, the usual age of the patient, are all strong factors in limiting the restoration of the functional activity of the shoulder-joint.

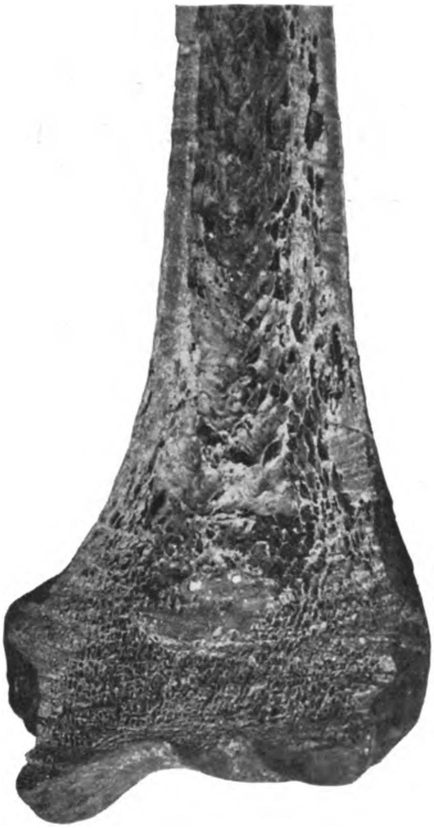


FIG. 52.—Section through the condyles of the humerus.

The mechanical application of the autoplastic peg transplant to fractures of the upper end of the humerus is best illustrated by a longitudinal section of a prepared specimen showing the peg imbedded in cancellous bone, across the line of fracture, resting upon the bony points of leverage which support the upper fragment (Fig. 53). The peg impinges on the hard, compact bone of the lower fragment at two points, *A* and *B*, and supports the upper fragment by firm contact at *C*. Mechanically the peg acts as a lever, with *A* as the fulcrum, *A B* as the long arm, and *A C* the short arm of the lever supporting the small fragment.

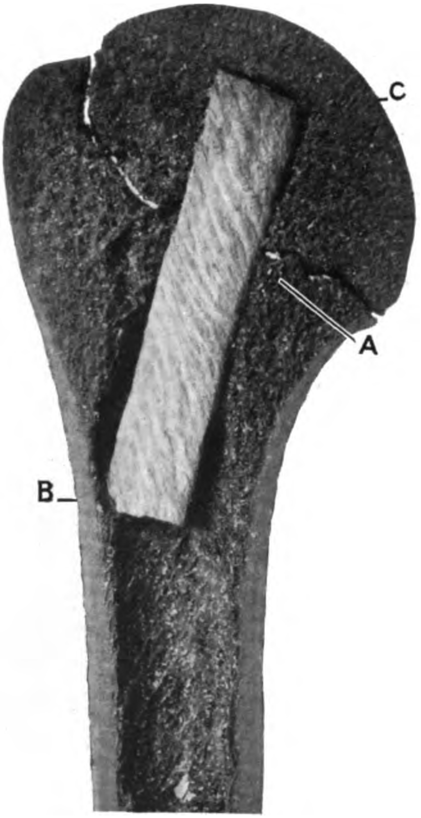


FIG 53.—Section of a prepared specimen of the peg transplant in fracture of the anatomical neck of the humerus.

The operation for autoplastic repair should be done either immediately after injury as a primary reduction, or after the subsidence of the acute symptoms of traumatism from the fracture or efforts at reduction. Langenbeck's incision for resection of the shoulder gives the best access to the fracture with the least disturbance of surrounding structures (Fig. 54). A longitudinal incision is made from the acromion process downward through the middle of the deltoid muscle to its insertion, separating rather than cutting the muscular fibers of the deltoid and exposing the fracture. The circumflex nerve must be avoided, as injury to it causes paralysis and atrophy of the deltoid muscle. The wound is cleared of blood-clots, exudate and detached fragments of bone. The character of the fracture is examined to determine the size and shape of the peg transplant required to support the upper fragment when resting on the points of compact bone contact of the lower fragment.

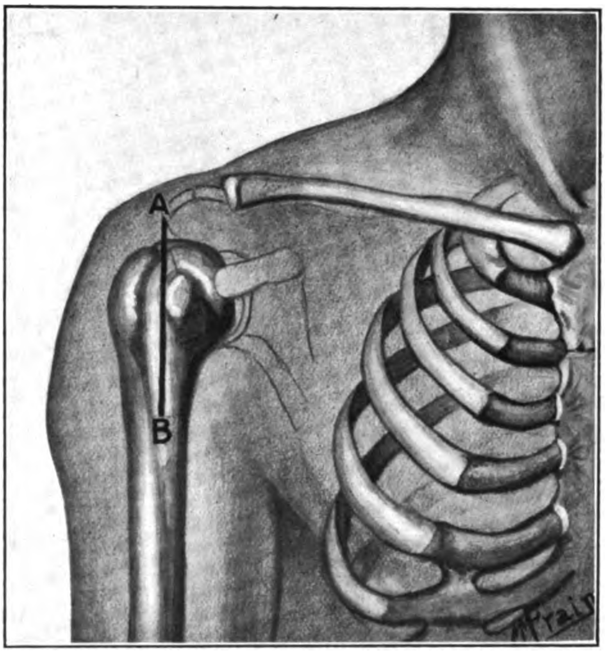


FIG. 54.—Langenbeck's incision.

The best material for transplantation in this fracture is secured from the crest of the tibia. Exact measurements of the necessary length and thickness can be determined by the use of calipers. The peg should be *rectangular*, so that when fitted into the cancellous bone the corners will impinge and prevent rotation of the head. A round peg transplant would permit rotation between the head and shaft. The periosteum should be removed from the transplant at its source. The transplant is accurately fitted to the lower fragment. The compact bone of the shaft at *B* (Fig. 53) is notched to receive the lower end of the transplant to give it proper stability. The transplant is removed from the lower fragment and fitted to the upper fragment. A canal is cut in the cancellous bone of the upper fragment in the centre up to the cartilage with a reamer, sharp bone spoon or small gouge. The canal must be smaller than the transplant, so that when the rectangular peg is driven into the canal it will bind sufficiently to hold the upper fragment from rotating or rocking from its proper alignment.

After the transplant has been fitted to both fragments, the exact rotation alignment of the fragments is determined, either by the irregularities of the fracture or by the known anatomical relation of the head of the humerus to the shaft. With the head in correct rotation the transplant is driven snugly into the canal in the upper fragment up to the cartilage. It must not be again removed or disturbed from its bed or its fit will be impaired. The lower fragment is bent at an angle and extended and manipulated until the lower end of the transplant can be made to enter and rest firmly in the place prepared for it. *While the wound is open and the repaired fracture in full view, an assistant secures the extremity to the side of the body with adhesive plaster.* The arm is placed straight down, with the forearm flexed against the thorax in such a manner that the rotation between the fragments shall not be changed. The wounds are closed in layers by absorbable sutures and dressed with gauze. The extremity is immobilized to the body by a plaster-of-Paris cast (Fig. 55).

If the fitting and introduction of the transplant has been accurately done with proper regard for the mechanical conditions of the individual fracture and properly immobilized during the time required for bone union, the end-results will be good. If the mechanical details are neglected or clumsily executed, or the graft imperfectly immobilized, the results will be bad.

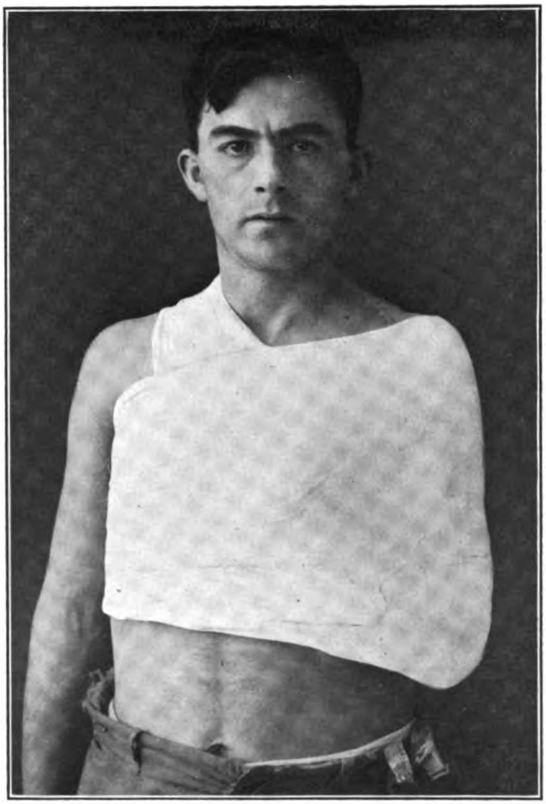


FIG. 55.—Position of immobilization of arm for autoplastic repair of fractures of the upper end of the humerus.

Early and complete restoration of function of the shoulder-joint follows the use of the autoplastic peg transplant for repair of this class of fractures. The head of the humerus presents its normal relation to the joint without deposition of callus impinging the articulation and checking the motion of the arm.

The following personal case shows an excellent result in a serious fracture of the anatomical neck of the humerus.

CASE No. 4.—Fracture of the anatomical neck of the humerus.—J. B.; American; teamster; aged forty-two years; was admitted to Cook County Hospital one day after he was struck by an automobile. Examination showed a man with the symptoms of fracture of the upper end of the left humerus. A röntgenogram revealed a fracture through the anatomical neck of the humerus (Fig. 56).

Operation for autoplastic repair of the fracture was performed ten days later. Incision over the fracture showed that the small fragment was rotated so that the ends of the fragments were not in apposition in any part. A canal was made in the cancellous bone in the upper fragment for the reception of the upper end of the peg transplant and a notch was cut in the medullary wall of the compact bone of the lower fragment to hold the lower end. A transplant, without periosteum, was taken from the spine of the tibia, by caliper measurements, to fit the space prepared for it in the fragments. The transplant was driven into the canal in the small fragment and the other end adjusted in the notch in the lower fragment. While the wound was open and the repair in full view, the forearm and elbow were fastened to the trunk by strips of adhesive plaster to retain by immobilization the position of rotation of the fragments. The wound was closed by catgut sutures in layers, dressed with sterile gauze and the extremity secured to the trunk by plaster of Paris for four weeks.

A röntgenogram taken five weeks after operation shows good position of the fragments with bony

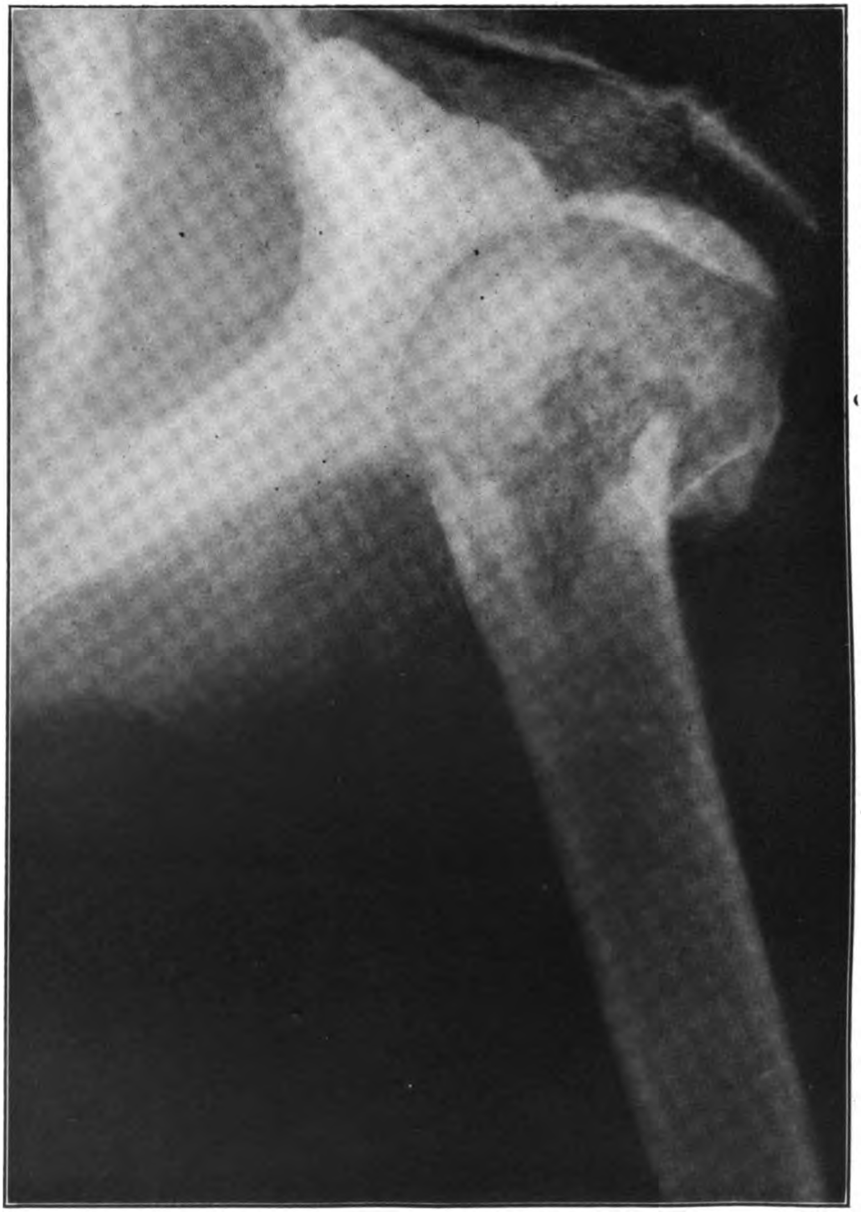


Fig. 56.—Case No. 4. Röntgenogram of fracture of the anatomical neck of the humerus.

union, with the transplant grafted to the surrounding bone (Fig. 57).

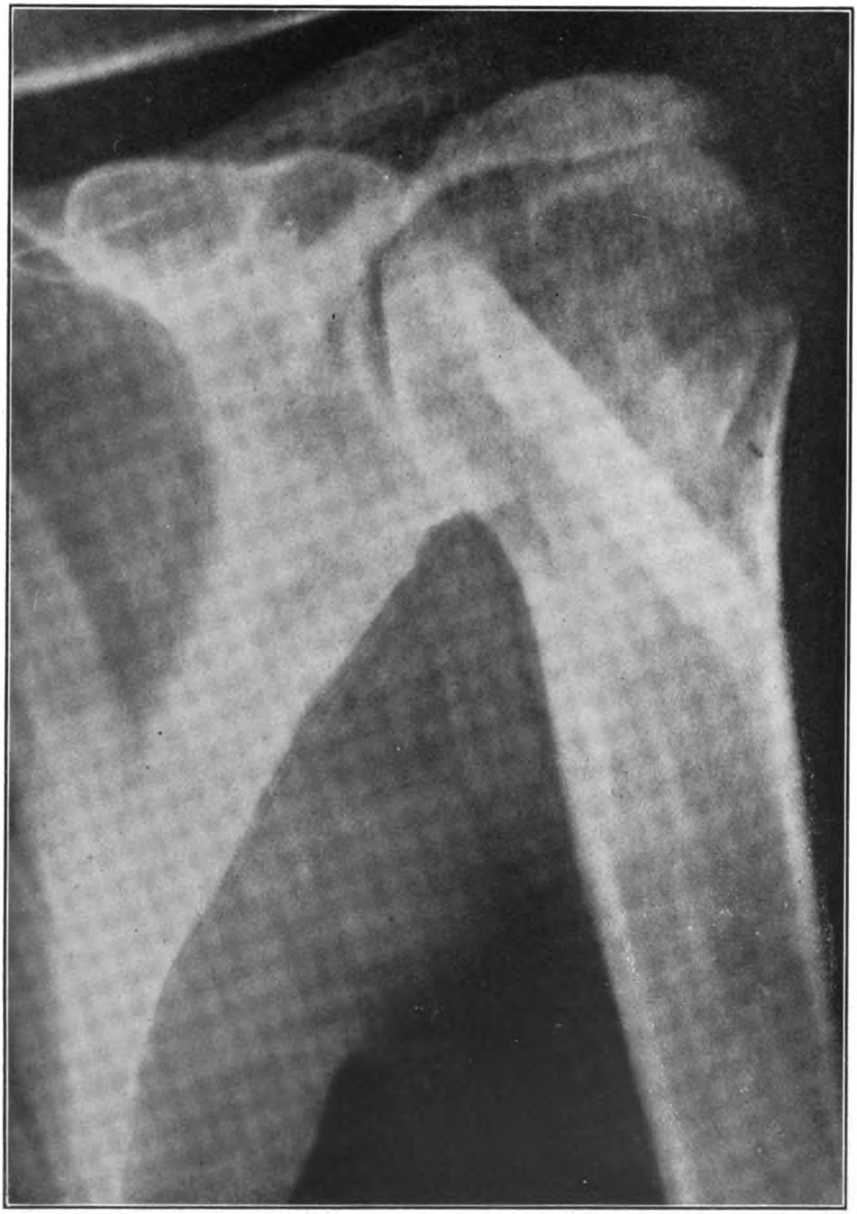


FIG. 57.—Case No. 4. Röntgenogram of head of the humerus, five weeks after operation, showing the peg transplant grafted to the fragments and union of the fracture.

The patient recovered with full functional use of the shoulder-joint.

The following personal case of autoplastic repair of fracture at the anatomical neck of the humerus, with severe comminution, in a dissipated old man, showed excellent anatomical and functional end-results.

Case No. 5.—Fracture of the anatomical neck of the humerus with comminution of the tuberosities.—J. T.; Irish; marine cook; aged forty-nine years; was admitted to Cook County Hospital March 3, 1914, suffering from an injury to the left shoulder produced by falling down a stairway while intoxicated.

Examination showed an elderly, dissipated man, with the left shoulder severely bruised and with pain and crepitus on manipulation of the shoulder. A röntgenogram showed a fracture of the anatomical neck of the humerus with comminution of the tuberosities and outward displacement of the head of the humerus (Fig. 58).

Open operation was performed five days later. Incision over the injury showed the tuberosities crushed and slivered into many small pieces and widely separated. The head was displaced outward and the joint was open.

An autoplastic peg transplant, 5 cm. long and 15 mm. thick and wide, without its periosteum, taken from the crest of the tibia, was imbedded in the cancellous bone underneath the cartilage of the head of the humerus and the other end of the peg secured in the medullary canal of the lower fragment, the transplant holding the head of the humerus like the handle of an umbrella. The fragments that remained attached to the periosteum and cartilage were placed around the peg. The wound was closed and the arm immobilized to the trunk in a plaster dressing.

Three weeks after operation the dressings were removed and union appeared to be firm. Manipulation of the arm showed that the head and shaft of the

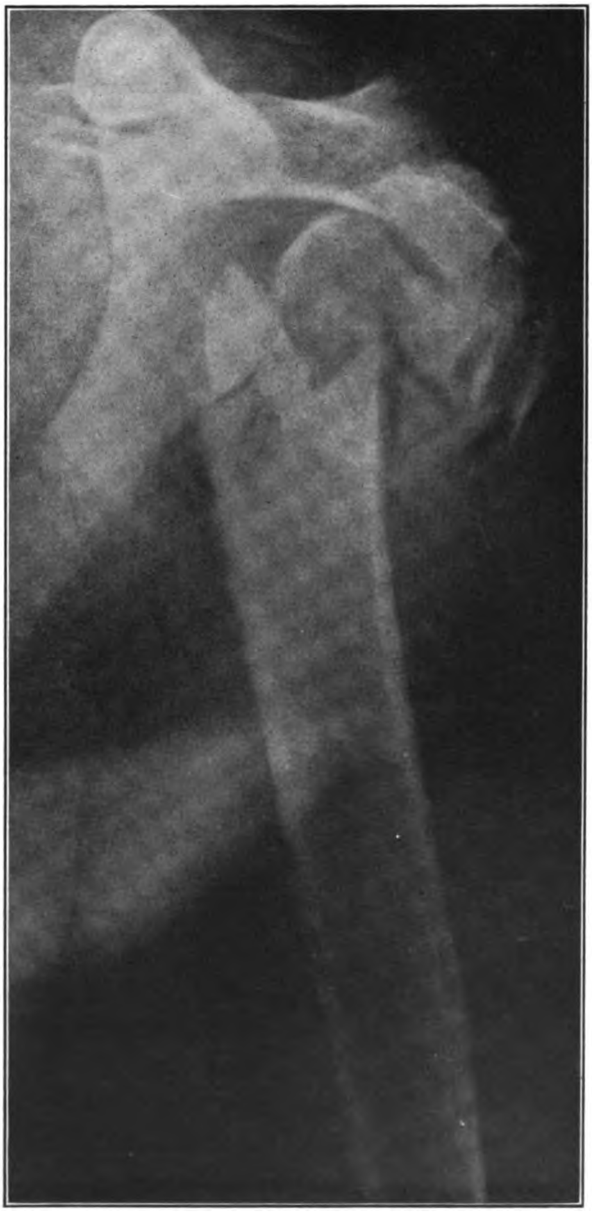


FIG. 58.—Case No. 5. Röntgenogram of comminuted fracture of the anatomical neck and tuberosities of the humerus.

humerus moved together during rotation and other movements of the arm. He left the hospital in another week with good use of his arm and shoulder.

A röntgenogram, taken eight months after the autoplastic fixation, shows the head of the humerus in position in the glenoid cavity; bony union of the fracture; considerable ragged callus not encroaching upon the joint; the autoplastic peg transplant intact in position across the healed line of fracture, grafted into the bone and forming an integral part of it with its edges blending into the recipient bone in every direction. The cancellous tissue of the head of the humerus appears infiltrated with new bone of the same type as the transplant from which it was generated (Fig. 59).

A röntgenogram, taken eighteen months after operation, shows extensive absorption of the new bone formation in the head of the humerus and partial absorption of the transplant (Fig. 60).

Recovery with a very mobile shoulder-joint resulted. The man reported that he had worked as cook on a lake steamer since he left the hospital without disability, discomfort or loss of time (Fig. 61).

2. FRACTURE OF THE SURGICAL NECK OF THE HUMERUS.—Any fracture below the epiphysial line and above the insertion of the pectoralis major and the teres major muscles may be regarded as a fracture of the surgical neck of the humerus.

Autoplastic repair of fracture of the surgical neck of the humerus should be done after a failure following reasonable efforts to secure good reduction with anatomical alignment and rotation and failure to secure efficient and stable immobilization of such reduction. The difficulties of good reduction and alignment of this fracture by traction and manipulation are great, because of the location and small size of the upper fragment. It is difficult to obtain the proper rotation reduction because of the uncertainty of the position or rotation of the small fragment incident to

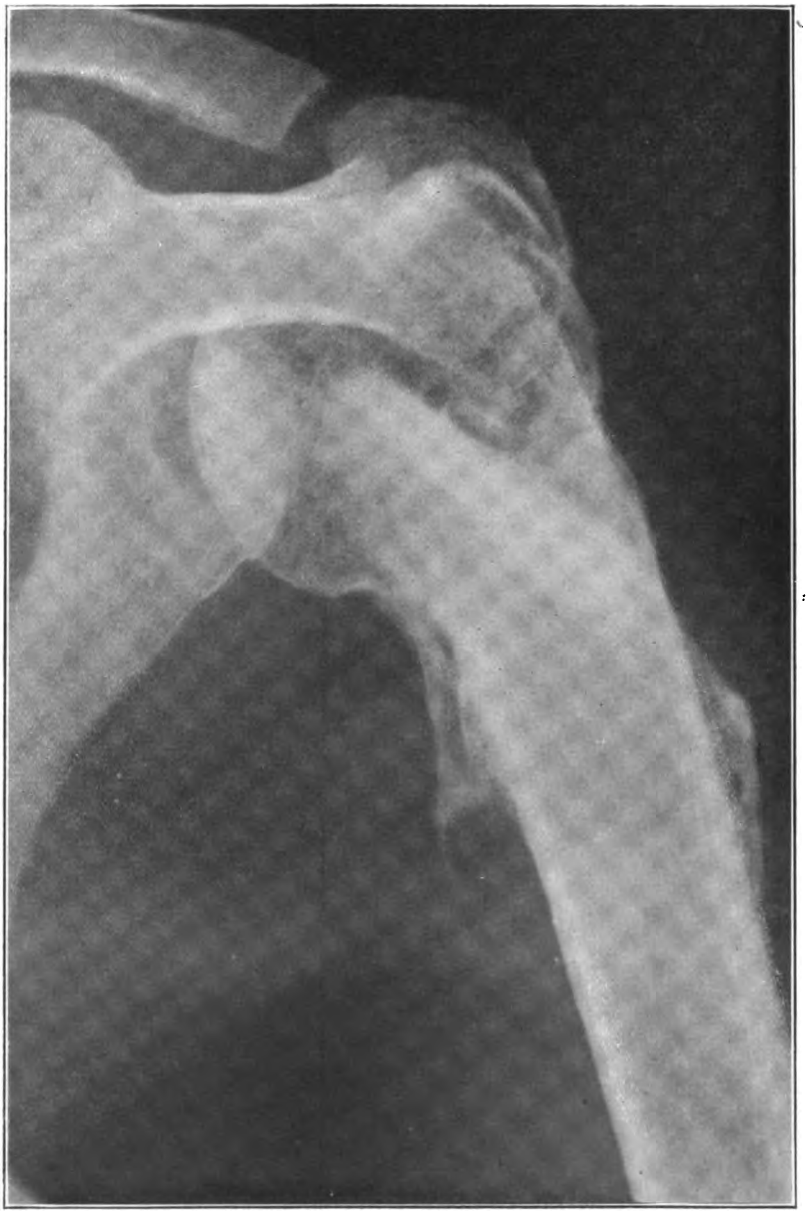


FIG. 59.—Case No. 5. Röntgenogram of head of humerus, eight months after operation, showing bony union of the fracture, with the transplant grafted in position across the fracture with deposition of new bone around it.

the injury. If anatomical reduction is successful, external fixation alone is insecure and uncertain.

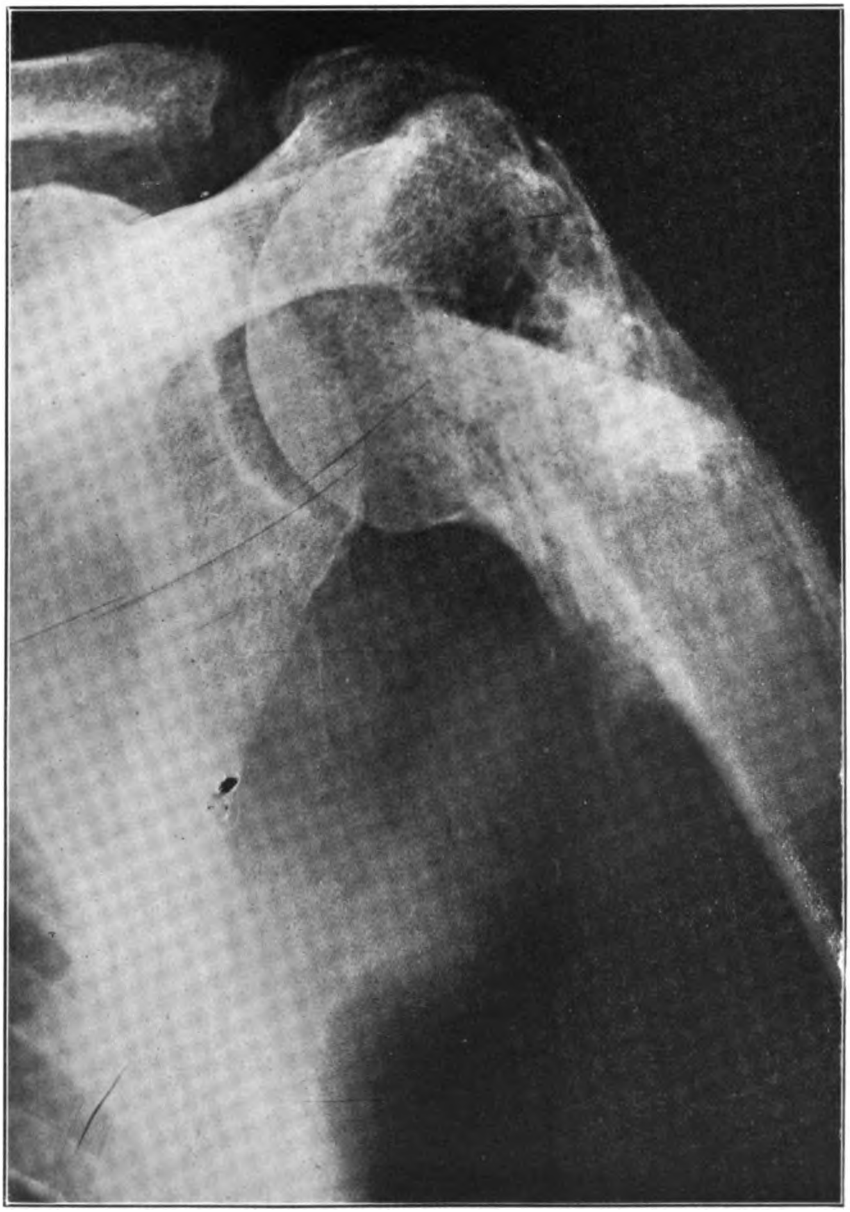


FIG. 60.—Case No. 5. Röntgenogram of head of humerus, eighteen months after operation, showing extensive absorption of the deposit of new bone with partial absorption of the transplant.

The manner of application of the autoplastic peg transplant to fractures of the surgical neck of the humerus is illustrated by a longitudinal section of a prepared specimen showing the transplant in position in the cancellous bone of the upper fragment and into the medullary canal of the lower fragment crossing the line of fracture (Fig. 62). The medullary canal of the lower fragment is expanded at the point of fracture and filled with marrow, while the interior of the upper fragment consists of soft, cancellous bone.

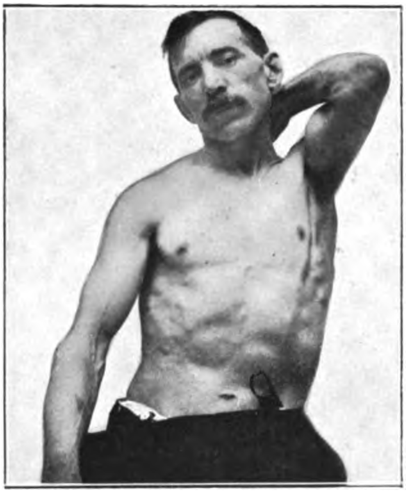


Fig. 61.—Case No. 5. Photograph showing the extent of voluntary motion.

The fracture is exposed by Langenbeck's incision, prolonged downward if necessary. The detritus caused by the injury is removed from around the fragments. The circumflex nerve and the vessels and nerves of the axilla are protected during the manipulation of the fragments.

The material for the peg transplant may be secured from the crest of the tibia or from the fibula. The transplant must be long enough to penetrate each fragment at least 2.5 cm. in addition to the length required to cross the line of fracture, which depends on the amount of irregularity and comminution of the fracture. If the transplant is secured from the crest of the tibia, its thickness and width must be regulated to give points of bony contact between it

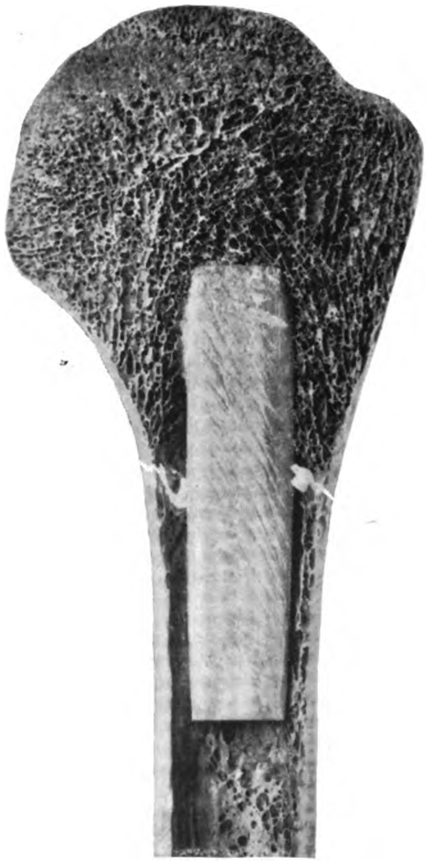


FIG. 62.—Section of a peg transplant in fracture of the surgical neck of the humerus.

and the wall of the medullary canal of the lower fragment. Measurements of the canal should be taken with calipers, and the transplant should be cut from the tibia of a size that will slip into the medullary canal the necessary distance without difficulty. The relative difference in size required to make irregular contact between an irregular quadrilateral body and the inside of a circle should be remembered and estimated. If the transplant is secured from the fibula, a section of the whole thickness of the fibula of the required length is taken from the lower part of the middle third of the bone. The periosteum is stripped off and allowed to remain at the fibular location.

The transplant is first fitted to the lower fragment, so that it will slip in and out without binding. The fitting is mostly done by scraping the wall of the medullary canal with a sharp bone curette at the points of contact of the irregularities of the transplant. An irregular quadrilateral transplant holds the fragments without rotation when properly placed, while a round-dowelled one allows rotation, even when well fitted.

The transplant is removed and fitted to the upper fragment. A canal, in the axis of the medullary canal of the humerus, is cut in the cancellous bone of the interior of the upper fragment. It is made deep enough to receive the requisite length of the transplant and small enough to bind it when forced into the canal. The transplant must not cross the epiphysial line in a growing bone. It will stimulate ossification between the epiphysis and the diaphysis, interfering with the continuation of the growth of the bone. The end of the transplant which has been fitted to the upper fragment is driven into its bed in the proper rotation to match the irregular fittings of the transplant to the lower fragment. It must not be again removed. The upper fragment is held with a Lowman's clamp. The lower fragment is manipulated so that the transplant can be slipped into the medullary canal in the space prepared for it. If the mechanical details of the operation have been well executed, the muscles quickly contract and hold the fragments in normal rotation and alignment. The irregular transplant acts as a key to prevent rotation.

The arm is secured to the thorax with adhesive plaster, by an assistant, while the wound is open and the repaired fracture is in view. The wounds are closed in layers without drainage. The extremity is immobilized with plaster of Paris (Fig. 55). The wound is not disturbed during convalescence. The bone apposition is so accurate that there is little disturbance of the shoulder-joint during convalescence, and its function is quickly and completely restored.

The following personal case of fracture of the surgical neck of the humerus illustrates the clinical results to be obtained:

Case No. 6.—Fracture of the surgical neck of the humerus.—E. K; Bohemian; school-boy; aged fourteen years; was admitted to the University Hospital one week after injury to the shoulder, with a history of having fallen twenty-five feet from the top of a ladder. Several attempts had been made to reduce the deformity without success.

Examination showed a strong, healthy boy, with an injury producing deformity with unnatural mobility of the right arm. A röntgenogram revealed a fracture of the surgical neck of the humerus with displacement and overriding of the fragments. A flange of bone on the upper fragment prevented reduction (Fig. 63).

Operation for reduction and autoplastic repair of the fracture was done August 29, 1914. A peg transplant without periosteum 6 cm. long and 1.2 cm. thick in each direction was removed from the patient's shin. It was fitted to the lower fragment and withdrawn, then fitted and driven into the cancellous bone of the upper fragment, avoiding the epiphysial line. The projecting end of the transplant was manipulated into the prepared medullary canal of the lower fragment. The wound was closed with catgut sutures,

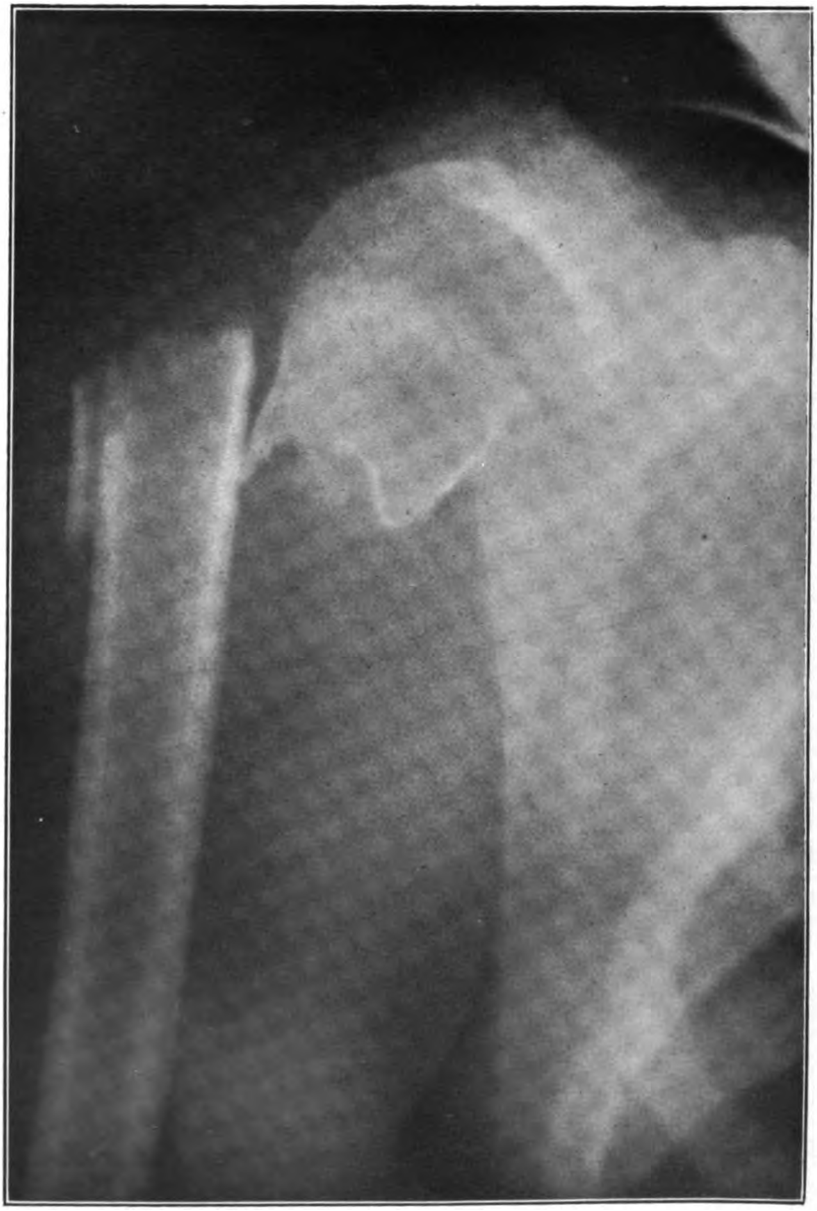


FIG. 63.—Case No. 6. Röntgenogram of fracture of the surgical neck of the humerus.

a large, sterile dressing applied, and the arm immobilized to the body, straight down, with plaster.

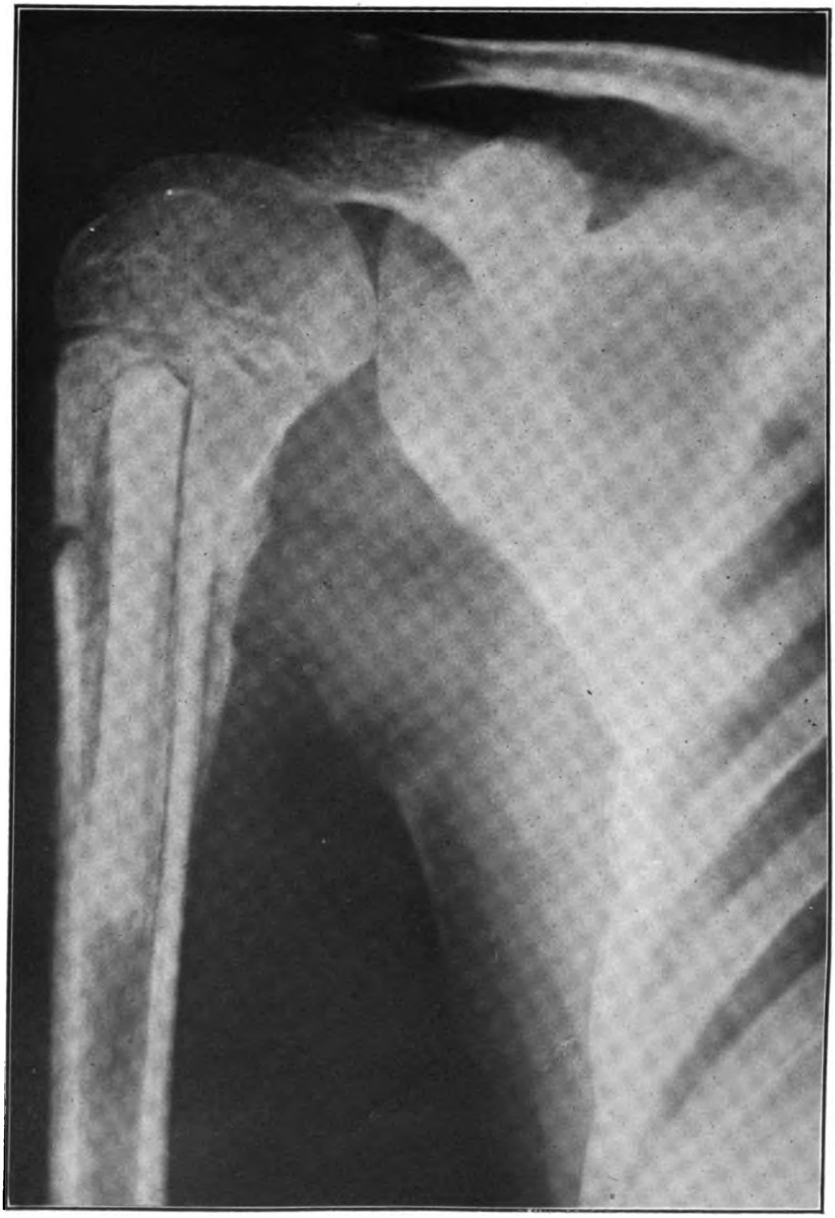


Fig. 64.—Case No. 6. Röntgenogram of autoplastic repair of fracture of the surgical neck of the humerus, five weeks after operation, showing the ransplant grafted across the line of fracture.

The wound was dressed twenty-four days later, when union of the fracture seemed firm and substantial.

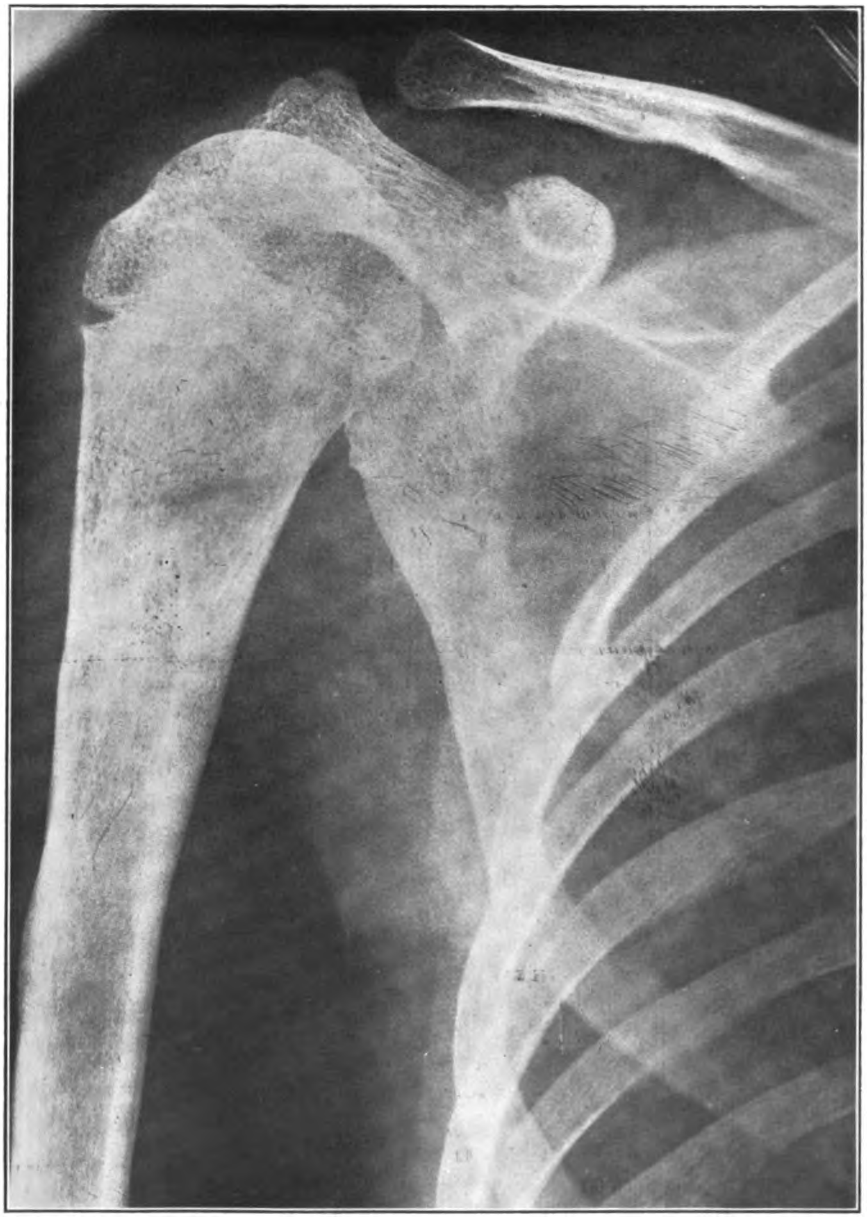


FIG. 65.—Case No. 6. Röntgenogram, one year after operation, showing almost complete absorption of the transplant.

Examination five weeks after operation showed solid, bony union and a perfect functional result. A röntgenogram taken at that time shows the alignment of the bone with the transplant in the medulla of one fragment and in the cancellous bone of the other across the line of fracture and also shows that the epiphysis has not been disturbed by the transplant (Fig. 64).

A röntgenogram, taken eight months after operation, shows complete bony union of the fragments, with the space in the region of the fracture filled with new bone of the same density as the transplant, almost obscuring it. A röntgenogram, taken one year after operation, shows almost complete absorption of the newly formed bone and the transplant (Fig. 65).

3. FRACTURE OF THE SHAFT OF THE HUMERUS.—Overriding of the fragments, which cannot be overcome by traction and manipulation, in fractures of the shaft of the humerus, should be corrected by open reduction with autoplastic fixation.

The application of the autoplastic medullary transplant to fractures of the shaft is illustrated by the diagram (Fig. 49) showing it in position in the medullary canal of the humerus across the line of fracture.

The fracture is exposed by an incision along the outer edge of the biceps muscle. The blood-clots and detritus are removed from the ends of the fragments.

The brachial vessels and large nerves of the arm must be avoided. The musculospiral nerve lies close to the posterior aspect of the humerus and may easily be injured at the time of the fracture or the operation.

The material for transplantation may be taken from the crest of the tibia or from the fibula. The transplant must be made long enough to extend into each fragment 2.5 cm. beyond the irregularities of the line of fracture. If it is obtained from the tibia, its lateral dimensions must be of sufficient size to give points of bone contact between it and the recipient fragments. It should be cut by caliper measurements enough larger than the medullary canal at the fracture to allow for fitting of points of bony contact. If it is obtained from the fibula, a portion of the whole thickness of the fibula the necessary length is taken from the lower part of the middle third of the bone. In either instance the periosteum is removed from it and left in its original location.

One end of the transplant is fitted to one fragment so that it will slip in and out. Its irregularities are shaped to the wall of the medullary canal to prevent rotation. The other end is fitted more snugly to the other fragment in the same rotation. It is driven into the canal the proper distance and is not again removed. The projecting end of the transplant is manipulated by flexion, traction and rotation of its fragment, until it enters the medullary canal of the fragment to which it was fitted. Muscular action forces the lower fragment against the upper. The transplant aligns the fragments in accurate reduction.

An oversized or ill-fitting transplant must not be driven into the medullary canal, because it will cause pressure necrosis at the points of contact and may split the fragment into which it is driven. If a fragment is split by forcing an ill-fitting transplant into its medullary canal, a strand of kangaroo tendon wrapped around it will bind the fragments. If the transplant is too loose and slips deeply into the medullary canal during the manipulation necessary to place the fragments in alignment, the distance that it may penetrate the medullary canal can be limited by a small steel drill passed through the humerus transversely at the distal end of the transplant and removed after reduction.

The wound is sutured and dressed in the same manner as for fracture of the anatomical neck of the humerus.

The following personal case shows favorable end-results in a severe spiral fracture of the shaft of the humerus, with overriding and deformity which was not reduced by repeated attempts, under ether anesthesia, by external manipulation.

CASE No. 7.—Fracture of the shaft of the humerus.—O. S.; American; clerk; aged thirty-seven years; was admitted to Cook County Hospital after injury to arm caused by falling from a porch while intoxicated. Examination showed a healthy-appearing man, with slight physical development and with an injury to his left arm, accompanied by abnormal mobility, angular deformity and shortening. A röntgenogram revealed a spiral fracture of the shaft of the humerus with slight comminution. The spiral defect was 7 cm. long and the fragments overlapped 3 cm. Reduction and immobilization by external means was not successful (Fig. 66).

Operation for the autoplastic repair of the fracture was performed February 10, 1914. A medullary transplant was taken from the crest of the tibia 13 cm. long and 1.2 cm. thick in each direction. It was inserted into the medullary canal of the humerus across the defect caused by the fracture, each end projecting into the corresponding fragment about 2.5 cm. to give support and stability to the fixation. The wound was closed by sutures, covered with abundant sterile dressings and the extremity carefully immobilized to the body by plaster of Paris to prevent change in alignment or any motion between the graft and its host.

Bony union with a palpable callus, a perfect line of continuity and a functional arm was present at

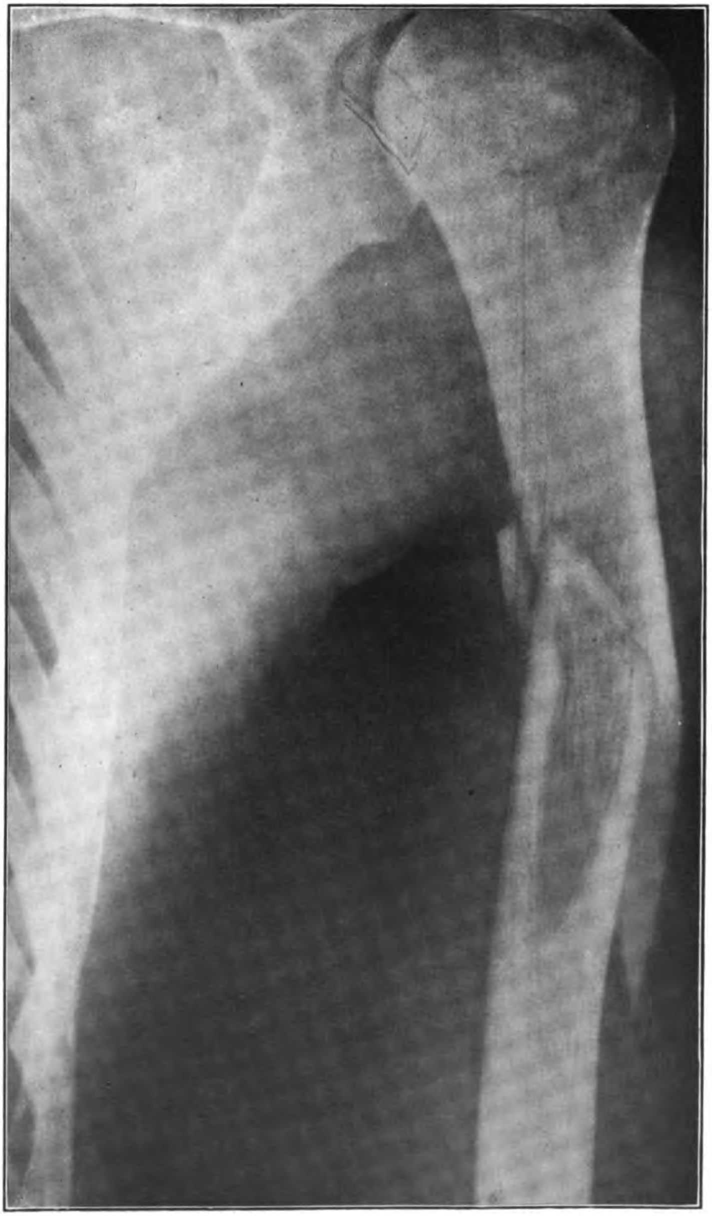


Fig. 66.—Case No. 7. Röntgenogram of spiral fracture of the shaft of the humerus.

the end of four weeks. The arm was protected for two weeks longer, after which he resumed his usual duties.

A röntgenogram, taken two months after operation, shows bony repair of the fracture with slight external callus, and the transplant grafted to the fragment across the line of fracture (Fig. 67). A röntgenogram, taken eighteen months after operation, shows partial absorption of the transplant. The lower portion of the graft has undergone much more absorption than the upper part opposite the comminution of the fracture, where the functional demands for support were greater and lasted longer (Fig. 68).

Good anatomical and functional recovery has resulted.

4. SUPRACONDYLAR FRACTURE OF THE SHAFT OF THE HUMERUS.—When there is such overriding of the lower fragment that it cannot be held in reduction by external immobilization, the fragments may be fixed in reduction by the autoplastic peg transplant, using almost the same technic of application as that used for fractures of the surgical neck. A posterior incision furnishes the best access to the fracture. The musculospiral, ulnar and median nerves must be avoided and protected from injury and callus.

5. FRACTURE OF THE INTERNAL OR EXTERNAL CONDYLE.—If, after capable efforts at reduction and immobilization, the condylar fragment is still so displaced that the articulation is disarranged, open reduction and autoplastic fixation of the condyle to the humerus in its normal position by a peg transplant is indicated.

The application of the peg transplant to fractures of the inner condyle is illustrated by a prepared section, showing it passing through the fragment and into the cancellous bone of the lower, expanded part

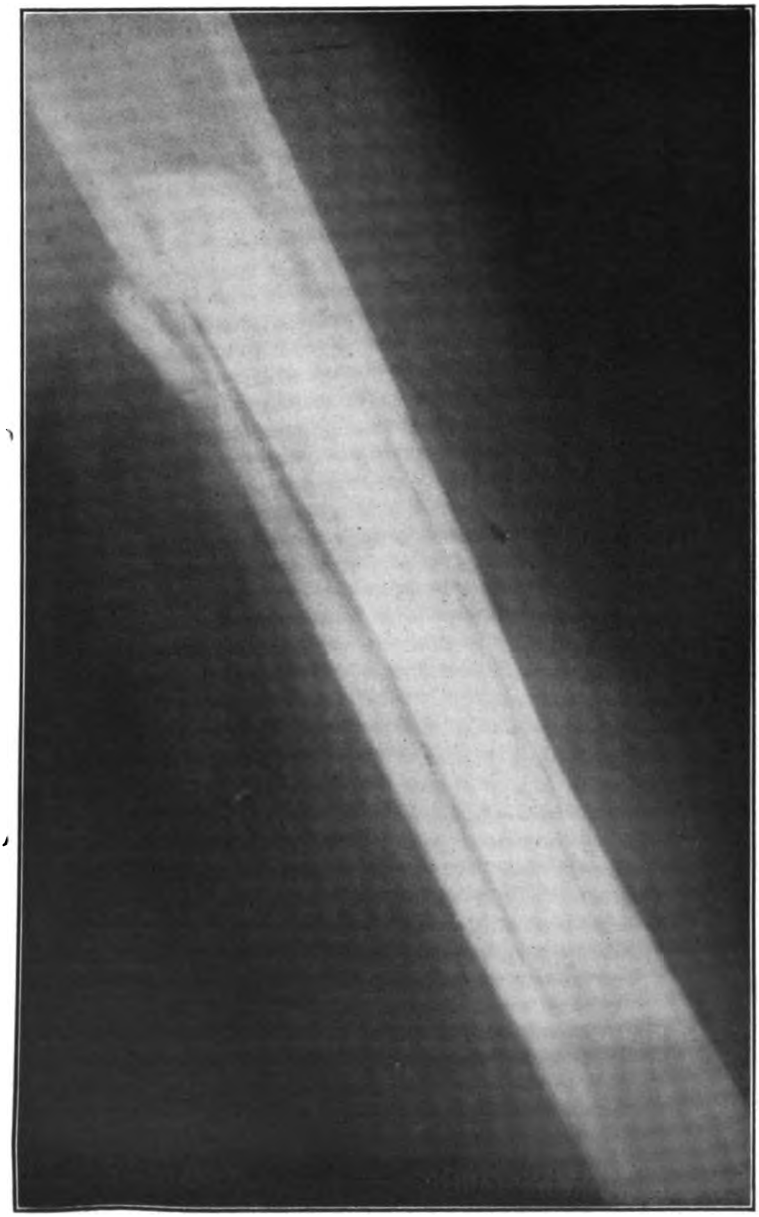


Fig. 67.—Case No. 7. Röntgenogram of humerus, two months after operation, showing the transplant grafted to the fragments with bony union of the fracture.

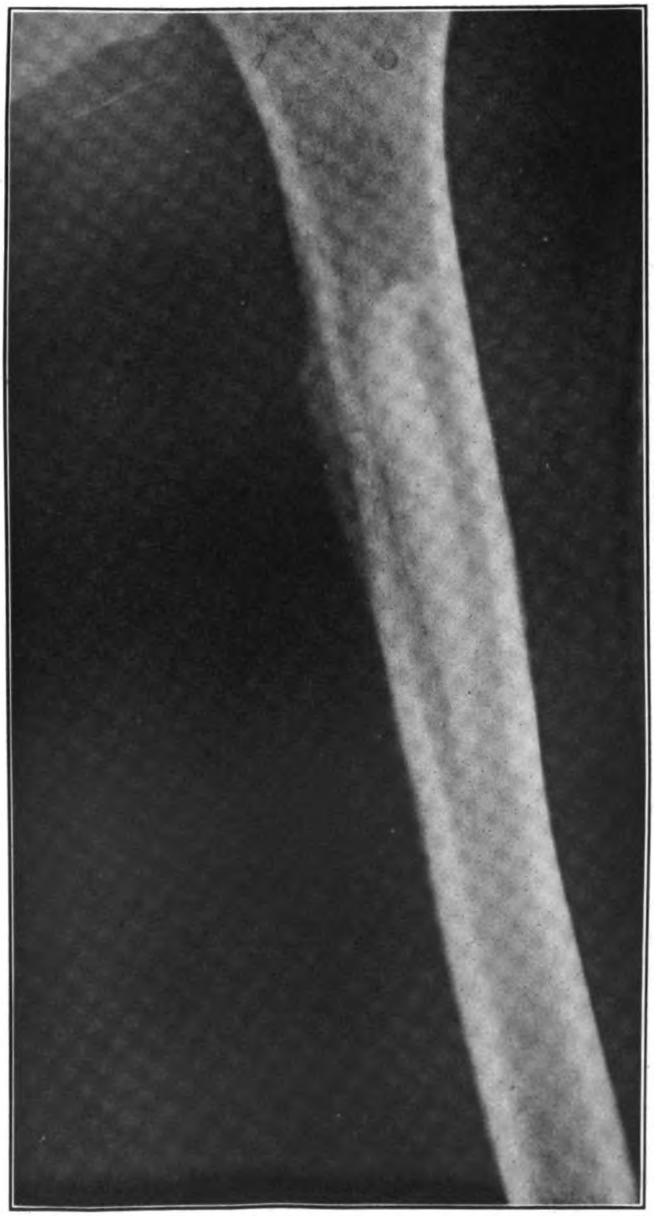


FIG. 68.—Case No. 7. Röntgenogram of humerus, eighteen months after operation, showing partial absorption of the transplant, especially at the lower end.

of the humerus (Fig. 69). The transplant penetrates above the olecranon fossa and impinges on the compact bone above the depression at *A*. It penetrates the compact bone of the internal condyle at *B* and of the humerus at *C*, giving three points of contact with compact bone. It acts as a lever, with *A* as the fulcrum, *A C* as the long arm, and *A B* as the short arm of the lever, supporting the condylar fragments.

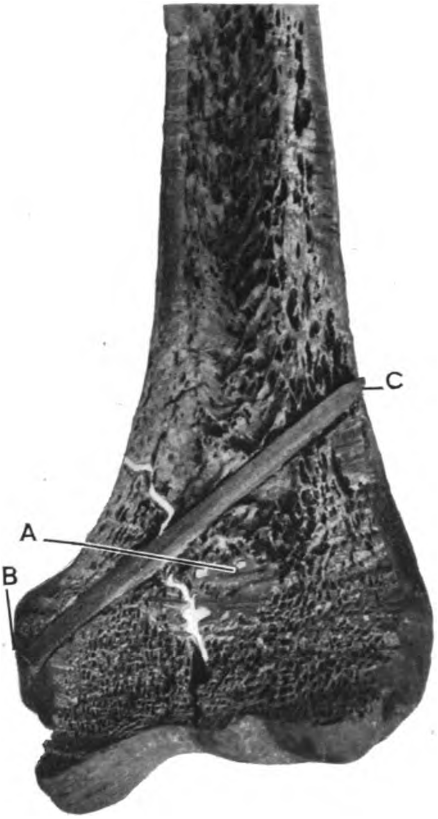


FIG. 69.—Section of a prepared specimen of a peg transplant in fracture of the humerus through the condyles.

An incision directly over the condyle gives good access to the fracture, avoiding the ulnar nerve if the inner condyle, or the radial nerve if the outer condyle is fractured. The displaced condyle is reduced and a hole is made, with a small drill, through the fragment across the line of fracture, through the adjacent cancellous bone above the olecranon fossa and through the opposite wall of the shaft. A quadrangular, tapering transplant is cut from the spine of the tibia, one end larger and the other end slightly smaller than the hole drilled across the line of fracture. The opening in the compact bone of the condyle is enlarged and fitted to the shape of the large end of the peg transplant, so that the condyle will not split when the transplant is driven through it. The tapering, angular peg transplant is driven into the round hole, binding the fragment in position. An accurately fitting, dowelled transplant will allow the condyle to rotate and change position, while the irregular, sawed peg will not. At the completion of the operation the extremity is immobilized with plaster with the forearm flexed.

In fractures of both condyles or T-fractures into the elbow-joint, each condyle can be secured by a separate peg transplant to the shaft of the humerus, the transplants crossing each other above the line of fracture, as illustrated by the prepared section of the lower end of the femur (Fig. 101).

FRACTURES OF THE FOREARM.

1. FRACTURE OF THE OLECRANON.—The olecranon is composed of an interior of cancellous, spongy bone surrounded by a thin wall of hard, compact bone (Fig. 70).

Fractures of the olecranon unite with fibrous union, unless treated by open reduction with accurate bone-to-bone apposition. The fractured olecranon may be accurately and securely fastened to the shaft of the ulna by an autoplastic peg transplant. The manner of its application is illustrated by a section of a prepared specimen, showing the transplant in position bridging the fracture and holding the fragment in apposition (Fig. 71).

The defect in the olecranon is exposed by an incision over the point of the elbow and the surfaces of the fracture are cleared of the interposed fibrous tissue. The fragments are held in reduction, while a canal is made with a drill diagonally through the small fragment across the defect in the direction to penetrate the shaft of the ulna, immediately below the coracoid process. A sawed transplant is taken from the spine of the tibia, without its periosteum, of a size which will fill the canal prepared for it, and which will not split the small fragment when it is driven into place. The transplant is driven into the canal like an iron nail until it is in contact with the hard bone of the shaft of the ulna. The tendinous fascia is sutured. The wound is closed by absorbable sutures. The elbow is immobilized with plaster of Paris in extension to relax the triceps muscle attached to the olecranon.

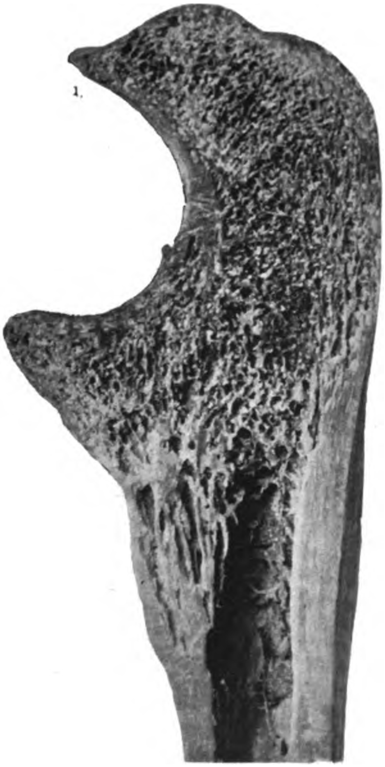


Fig. 70.—Section of olecranon, showing the arrangement of cancellous bone.

2. Fractures of the Radius and Ulna.—When fractures of both bones of the forearm cannot be

reduced by external methods and when open reduction does not hold by contact, autoplastic fixation is indicated.

Whichever bone is larger at the point of fracture may be fastened by a medullary transplant. A small, medullary transplant is obtained from the ulna below the olecranon or from the crest of the tibia. Only one bone can be fastened by transplants, as it would be necessary, if both bones were fixed, to enter both transplants into the medullary canals of the second fragments simultaneously, which would be difficult. It is sufficient to fix the fragments of the larger bone with a transplant and to fasten the ends of the fragments of the smaller bone with kangaroo tendon.

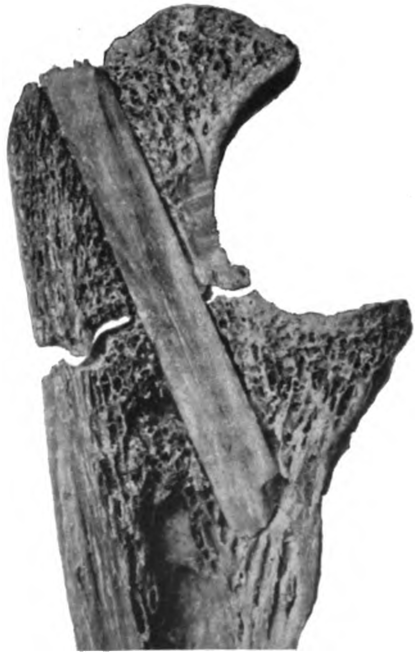


FIG. 71.—Section of a prepared specimen of a peg transplant in fracture of the olecranon.

The forearm when dressed should be flexed midway between pronation and supination; immobilized by plaster dressings.

The following personal case illustrates the successful use of the medullary transplant in the radius, in fracture of both bones of the forearm in the lower third, which had not responded to the usual methods of reduction.

CASE No. 8.—Fracture of radius and ulna.—I. E.; Russian Jew; laborer; aged sixteen years; was admitted to Cook County Hospital June 6, 1914, with history of injury to arm by falling while playing ball.

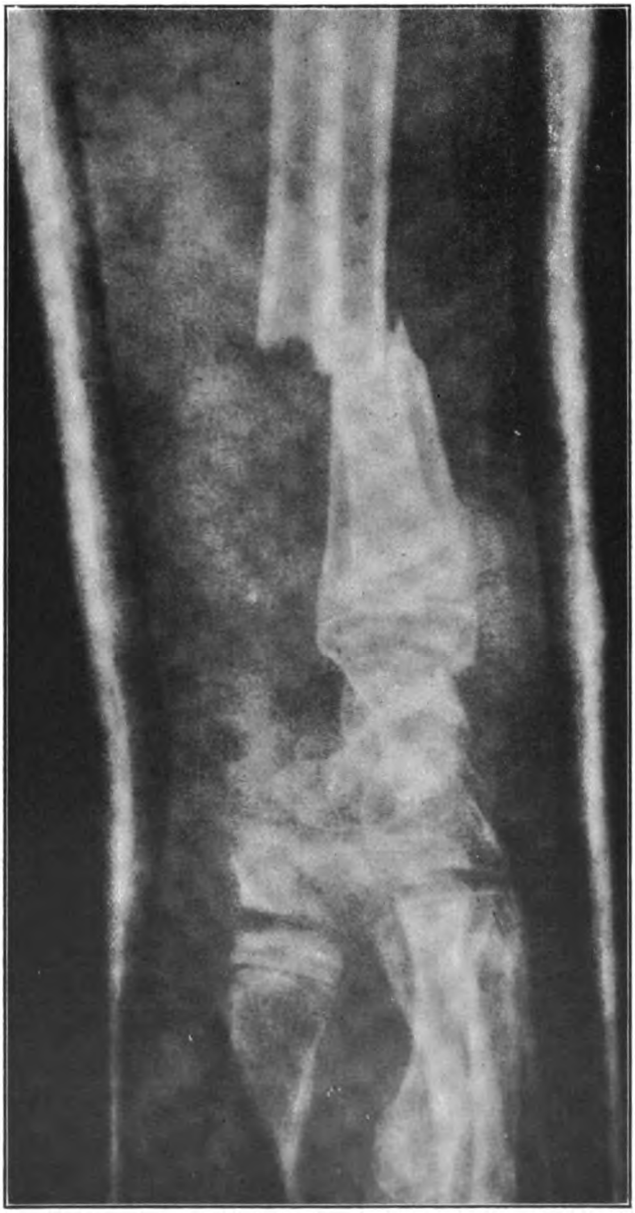


Fig. 72.—Case No. 8. Röntgenogram of fracture of radius and ulna.

Following three careful attempts at reduction, under anesthesia, a röntgenogram showed that the fragments were not in alignment (Fig. 72).

Twelve days after admission to the hospital reduction by open operation, with fixation of the radius by a medullary transplant, was done. A small transplant, without periosteum, was secured from the crest of the tibia. It was introduced into the medullary canal of the radius across the line of the fracture. Alignment with good, stiff support of the fragments of the radius was secured. The fragments of the ulna, smaller in the lower third of the forearm, showed little tendency to displacement after the radius was fixed, but to make the fixation doubly secure, they were fastened together by a kangaroo-tendon suture (Fig. 73).

Convalescence was uneventful. Union appeared to be firm at the first dressing, three weeks after operation. He left the hospital one week later with good bony union of the fracture and a functionally perfect arm.

FRACTURES OF THE FEMUR.

SPECIAL ANATOMY.—A longitudinal section through the femur shows the shaft to be a cylinder of compact, dense bone, thick and strong at the middle and expanding toward the ends, with a central, nearly circular medullary canal filled with marrow. The medullary canal is smallest at about the junction of the upper and middle thirds of the shaft. It abruptly expands at its upper end as it meets the cancellous bone of the trochanteric region. It gradually expands in the lower third of the shaft until it meets the cancellous bone of the condylar region. In the location where the canal is small, the shaft is small, but the compact bone is correspondingly dense, thick and strong. Where the canal is larger, the compact bone is expanded and

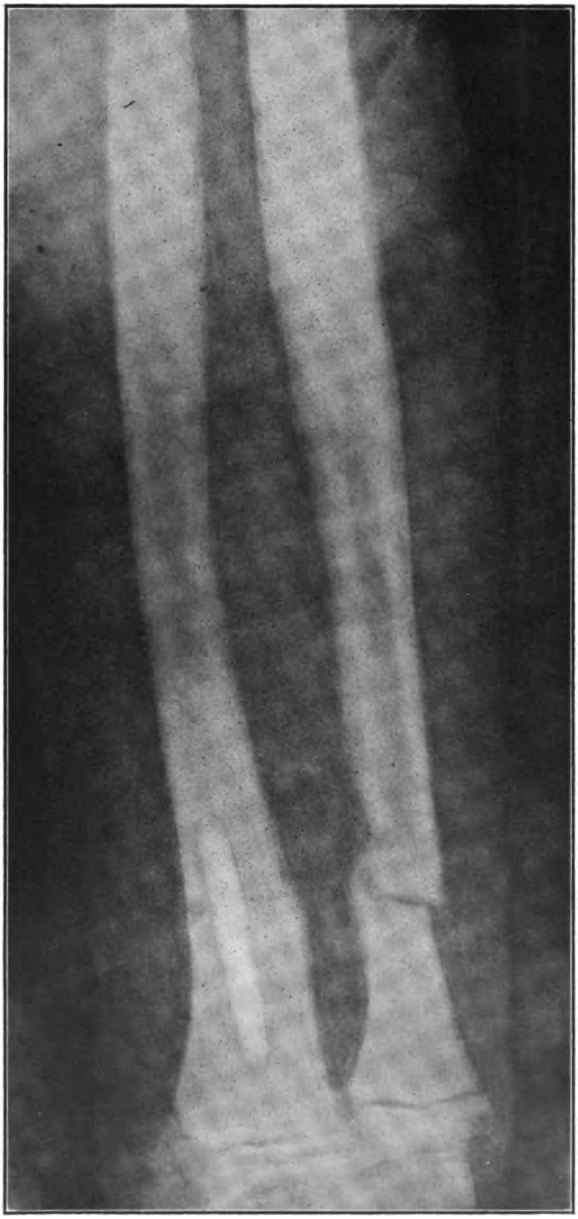


FIG. 73.—Case No. 8. Röntgenogram of radius and ulna, showing medullary transplant in the radius.

correspondingly thinner (Fig. 74). The upper and lower ends of the femur consist of tough cancellous tissue invested by a thin layer of compact bone (Figs. 75 and 76).

1. **Fracture of the Neck of the Femur.**—This fracture is rarely reduced by traction or position, because the small fragment cannot be controlled by external manipulation of any kind. It is rarely held in immobilization with the proper extension for a sufficient length of time for bony union to occur, even if reduction had once been accomplished.

The prognosis in unimpacted fracture of the neck, when treated expectantly, is bad. The union of the fracture is usually fibrous and the functional end-results are poor.

Fractures of the neck of the femur when unimpacted demand autoplastic fixation of the fragments in their normal anatomical relation, unless the physical condition of the patient contraindicates the necessary surgical interference.

The mechanical application of a peg transplant to this fracture is shown by a longitudinal section of a prepared specimen,

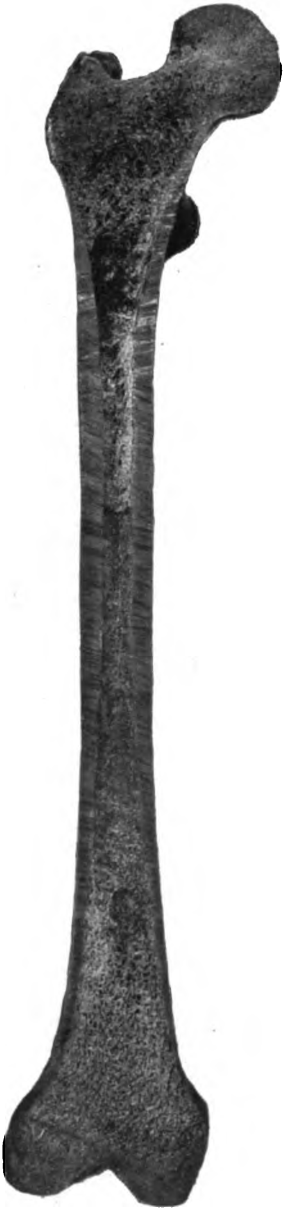


Fig. 74.—Section of entire femur, showing the medullary canal and the arrangement of cancellous bone.

showing a segment of fibula across the line of fracture impinging upon three bony points of leverage which support the head and neck in their normal anatomical alignment (Fig. 77). The transplant rests at *A* on a strong mass of compact bone reinforced by the base of the lesser trochanter. The lower end is held securely in the opening made for it in the compact bone of the shaft at *B* and the upper end is firmly imbedded in the transitional bone against the cartilage at *C*. The transplant is placed so that

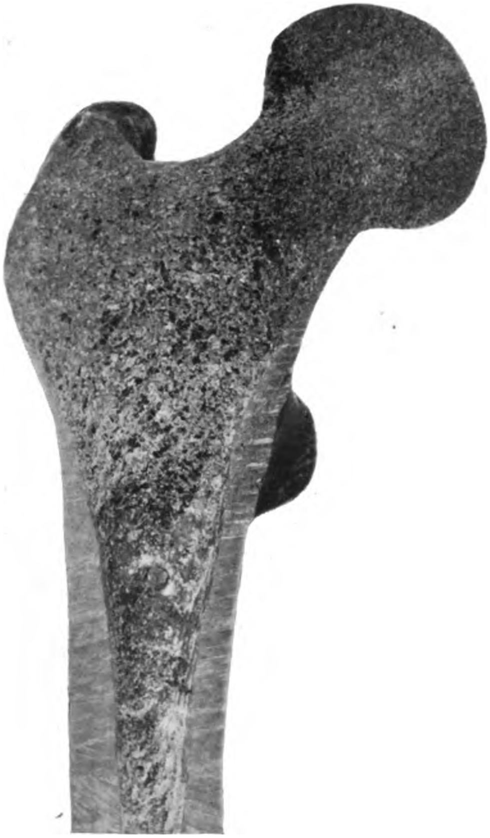


Fig. 75.—Section of upper end of femur, showing the arrangement of cancellous bone.

it acts as a powerful lever, with *A* as the fulcrum, *A B* acting as the long arm and *A C* as the short arm of the lever supporting the upper fragment. The wide angle (*C A D*) of about 135 degrees between the peg and the axis of the shaft of the femur materially increases the mechanical strength of the autoplastic repair at the line of fracture and substantially increases the resistance of the peg to cross-breaking strain at the line of fracture when the weight of the body is sustained in walking. The upper end of the transplant impinges against the cartilage of the head of the bone

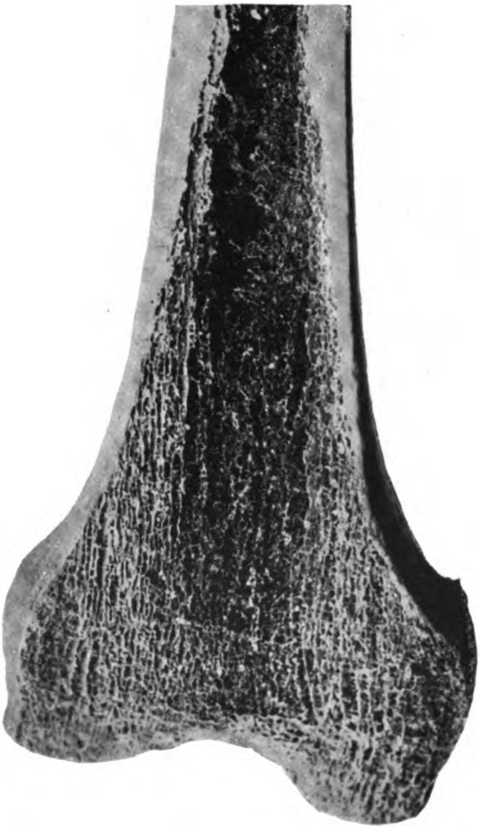


FIG. 76.—Section through the condyles of the femur.

above the depression for the attachment of the ligamentum teres, otherwise the nutrient artery of the head of the bone which enters through the ligamentum teres might be destroyed and necrosis of the upper fragment occur. The firm bone at the point of the depression to receive the ligament is correspondingly thinner and would give less support for the transplant.

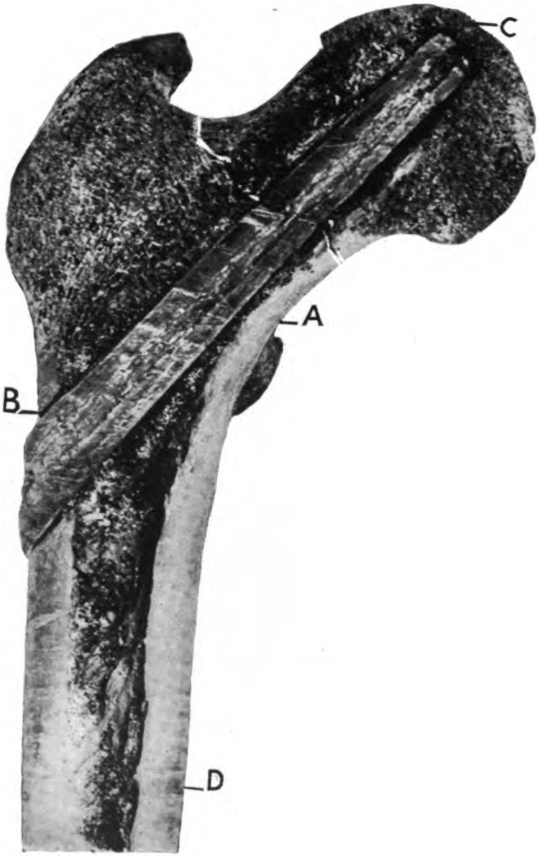


Fig. 77.—Section of a prepared specimen of a peg transplant in fracture of the neck of the femur.

The operation for repair of fracture of the neck of the femur by the use of the autoplastic peg transplant is outlined as follows: The patient is placed in position on a Hawley fracture operating table. The fracture is exposed by an anterior incision, beginning a little below the anterior superior spine of the ilium, extending downward. The detritus and soft parts, if any, are removed from between the ends of the fragments. A second incision is made along the outer aspect of the thigh, exposing the greater trochanter and the shaft of the femur immediately below it. Accurate reduction of the fragments is accomplished as seen through the anterior incision. An opening is made through the cortex in the outer part of the shaft, with a gouge and hammer or electric drill, at the level which will give the angle of leverage previously illustrated. The fragments are held firmly in reduction, while a canal, slightly smaller than the transplant to be used, is cut with a hand reamer through the opening previously made in the shaft. The canal extends through the cancellous bone across the line of fracture to the cartilage of the head of the femur above the depression for the ligamentum teres. The hand reamer is preferred to prevent the extension of the canal beyond the capital fragment into the cavity of the hip-joint. Accidental perforation of the acetabulum is easily done with an electric drill. The length of the canal is measured to obtain the length required for the transplant. A segment of the lower part of the fibula of the proper length is used for the transplant. The periosteum is removed from it and left in its original location.

The fibula is selected as the source of the peg transplant because:

(*a*) It is the size of bone adapted to the purpose.

(*b*) The requisite length is easily obtainable.

(*c*) It is irregularly round and will not rotate like a dowelled peg.

(*d*) It is a tube of compact bone which is mechanically stronger than the same amount of compact bone in a solid piece.

(*e*) It is lighter than a solid, sawed peg.

(*f*) Its elasticity is greater than a solid transplant, more closely conforming to the elastic character of a normal neck of the femur.

(*g*) It is filled with undisturbed marrow which aids in the viability of the transplant.

(*h*) It presents a continuous circular surface of the cambium layer to the host bone for grafting and to stimulate osteogenesis in and around the defect.

The opening in the shaft of the femur is enlarged and fitted to the large end of the transplant to prevent splitting of the femur when the transplant is driven through its cortex. With the small fragment in alignment, the transplant is driven into the canal, across the line of fracture, until the end rests against the under surface of the cartilage of the head of the femur. The transplant, when properly applied, holds the small fragment with a strength equal to the cross-breaking strain required to break it at the line of the repaired fracture. The wounds are closed in layers by catgut sutures, covered with sterile gauze and the extremity immobilized.

It is essential to the grafting process that the transplant remains in stable contact with the recipient bone, without any motion whatever between them, to accomplish which, all muscular spasm and all leverage movement on the transplant at the line of fracture must be prevented. Muscular spasm can be prevented by immobilization of the extremity in a neutral muscular position. Abduction and outward rotation of the thigh relaxes the muscles attached to the greater trochanter; flexion and outward rotation of the thigh relaxes the iliopsoas muscle; abduction of the thigh causes the iliopsoas to pull the fragments directly together, after reduction, in fracture of the neck of the femur; flexion of the leg on the thigh relaxes the hamstring muscles; consequently, to neutralize muscular action, to prevent spasm and intermittent movement between the transplant and recipient fragment, the thighs are placed in extreme abduction and extreme outward rotation and slight flexion on the trunk. During immobilization, if a short spica is used, the patient will be able to tilt the pelvis and change the position of the hip-joint on the injured side by bending the spinal column; consequently, the spinal column is immobilized by a wide body cast. If the opposite hip-joint is allowed to remain free, the patient will be able to tilt the pelvis and shift the position of the fragments; consequently, it is immobilized by including the uninjured thigh in abduction in the cast.

Immobilization is accomplished by a strong plaster-of-Paris cast extending from the axilla to the toes and including the opposite thigh, with the injured extremity in the position of extreme abduction and extreme external rotation (Fig. 78). The immobilization should be continued without change or disturbance from eight to ten weeks and weight-bearing should be prohibited until the functional mobility of the hip-joint has been reëstablished. The cast may be fenestrated without disturbing the immobilization, if access to the wound of operation becomes necessary.

The Fowler position during early convalescence is advisable, as it prevents many of the complications caused by continued dorsal decubitus, especially in old or debilitated people (Fig. 79).

The following personal case illustrates the use of a segment of fibula for the autoplastic repair of recent fractures of the neck of the femur.

CASE No. 9.—Fracture of the neck of the femur.—A. D.; Irish; laborer; aged sixty-three years; alcoholic; slipped on the ice and injured his left hip. He was admitted to Cook County Hospital at once, February 2, 1915.

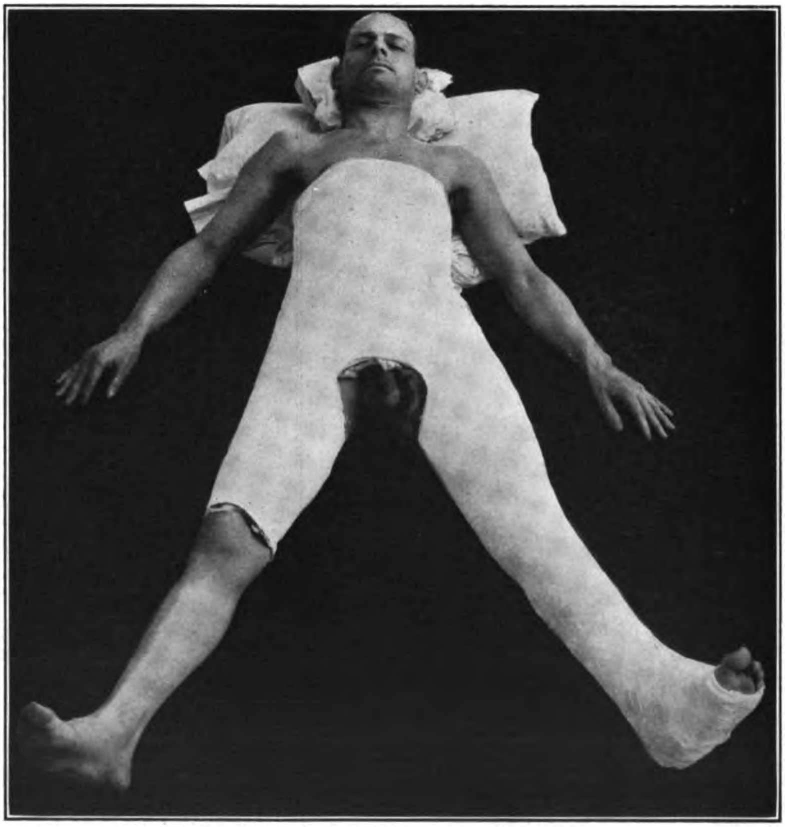


FIG. 78.—Position of immobilization *required* in autoplastic repair of the upper part of the femur.

Examination showed an old man with a painful hip, a helpless lower extremity in abduction with eversion of the foot. There was 3 cm. shortening on the injured side. A röntgenogram showed a fracture of the neck of the left femur (Fig. 80).

Operation for autoplastic repair of the fracture was performed four days later, under ether-oxygen anesthesia, on a Hawley fracture table. The fracture was exposed by incision, cleared of detritus and reduced.

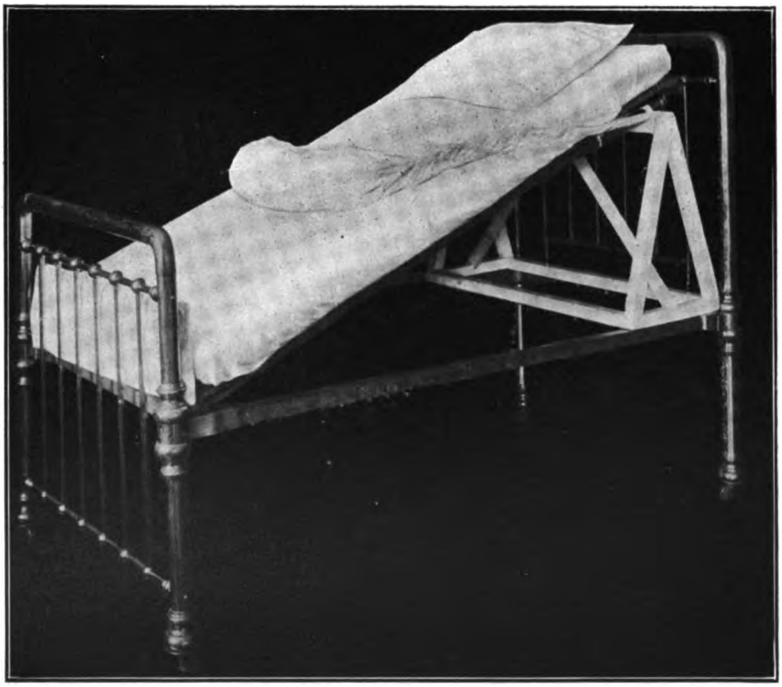


FIG. 79.—Bed prepared for Fowler's position.

An incision was made over the greater trochanter and extended downward. A point on the shaft of the femur below the greater trochanter which would give the proper angle for the insertion of the transplant was selected, and a canal cut with a reamer upward and inward, across the line of fracture, through the cancellous structure of the neck, into the head of the bone. A peg transplant was taken from the lower part of the fibula of the same extremity. A segment of the whole thickness of the bone, without perios-

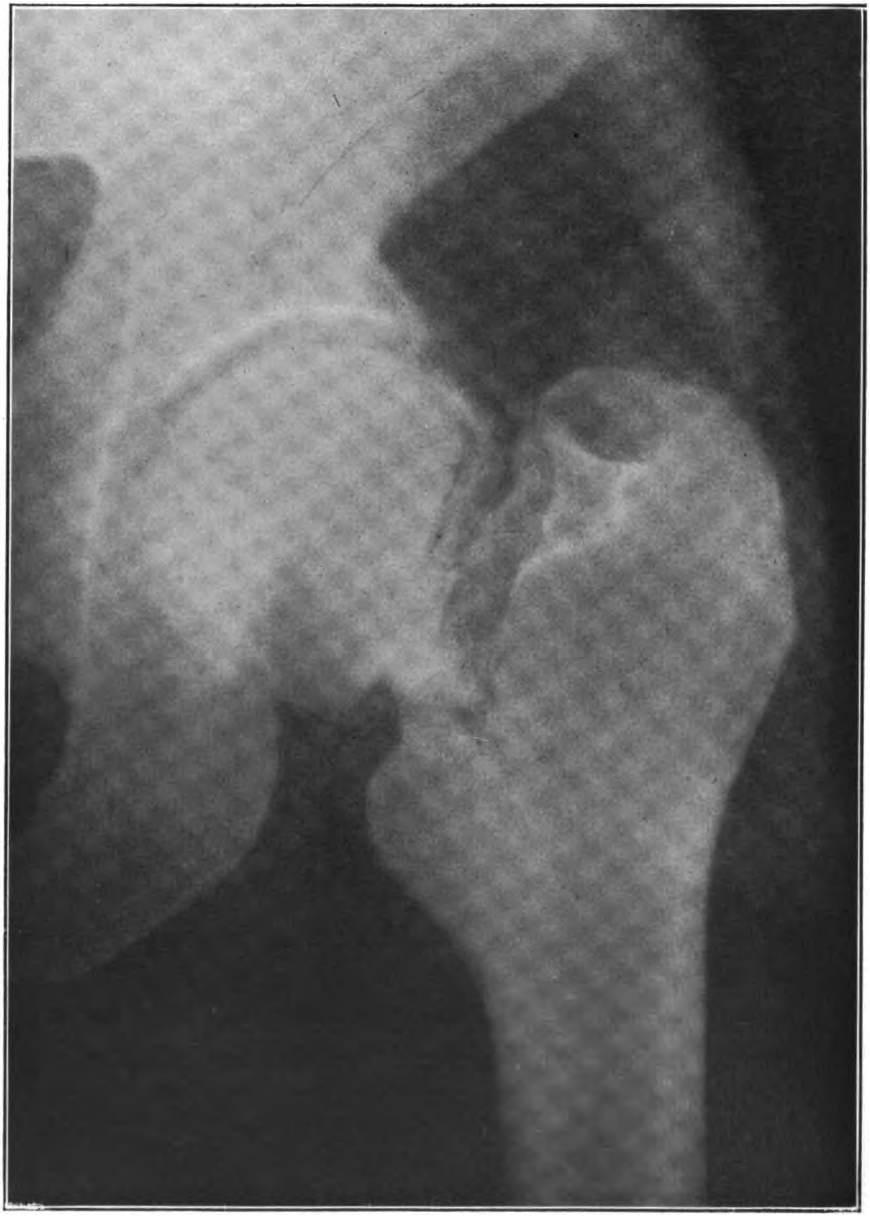


FIG. 80.—Case No. 9. Röntgenogram of fracture of the neck of the femur.

teum, 11 cm. long was used. The opening in the shaft of the femur was accurately fitted to the irregularities of the larger end of the transplant, so that it would not split the femur when driven into the canal or rotate when in position. The transplant, with the small end first, was driven snugly into the canal. The thigh was placed in extreme external rotation and extreme abduction to relax the muscles attached to the greater trochanter. The wounds were closed with catgut sutures in layers and dressed with sterile gauze. The hip-joint was immobilized by a body plaster-of-Paris cast extending to the axilla, to the toes on the injured extremity and including the opposite thigh.

Union of the fracture had occurred when the cast was removed at the end of eleven weeks.

A röntgenogram, taken six months after operation, shows the peg transplant grafted across the line of fracture, with bony union between the fragments (Fig. 81). At that time the patient also had good adduction, internal rotation and flexion of the extremity (Figs. 82 and 83).

Conclusions.—In the autoplastic treatment of fractures of the neck of the femur, three points are of importance:

1. The use of a section of the fibula for the peg transplant.

2. The introduction of the peg transplant at an obtuse angle to limit the cross-breaking strain, when possible an angle with the shaft of the femur of 135 degrees.

3. Complete immobilization in a position to neutralize muscular action, *i. e.*, in extreme abduction, extreme external rotation and slight flexion of the thigh.

The transplant will be sheared across at the line of fracture or will cut through the host bone if these three points are not strictly followed.

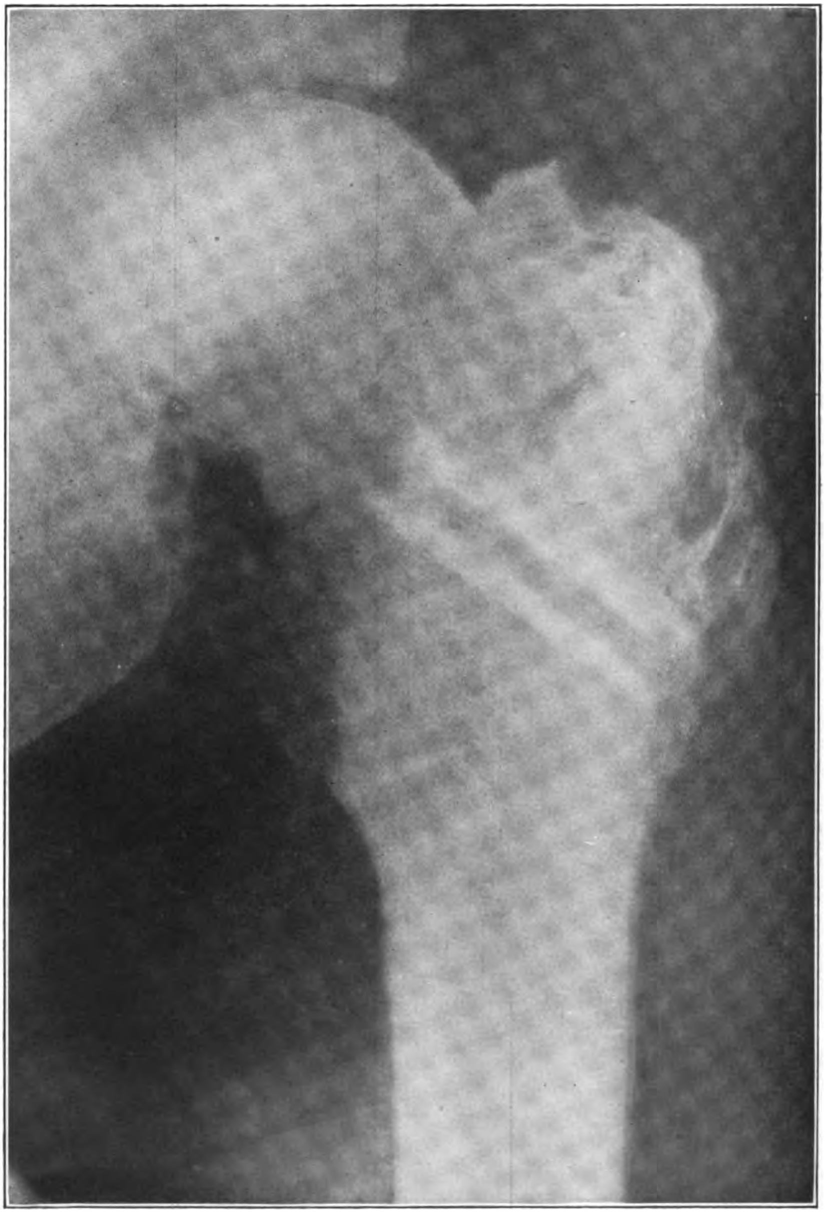


FIG. 81.—Case No. 9. Röntgenogram of autoplastic repair of fracture of the neck of the femur, six months after operation, showing the peg transplant grafted across the line of fracture with bony union of the fracture. It also shows marked arteriosclerosis of the femoral artery.

The history of the following case illustrates the conditions at the line of fracture and around the fibular transplant twenty-three days after operation.

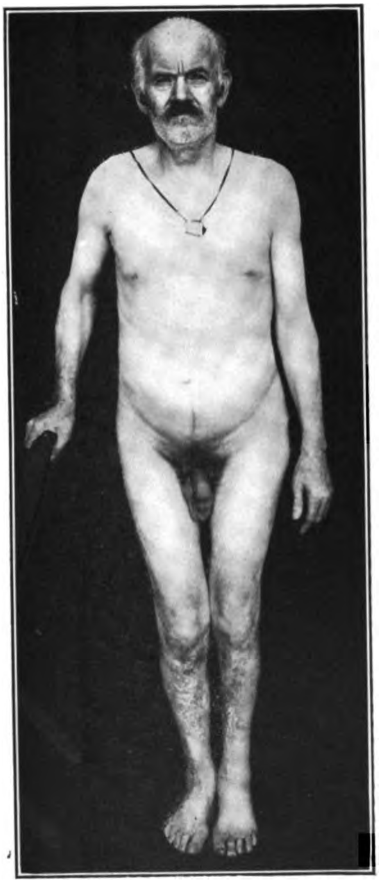


FIG. 82

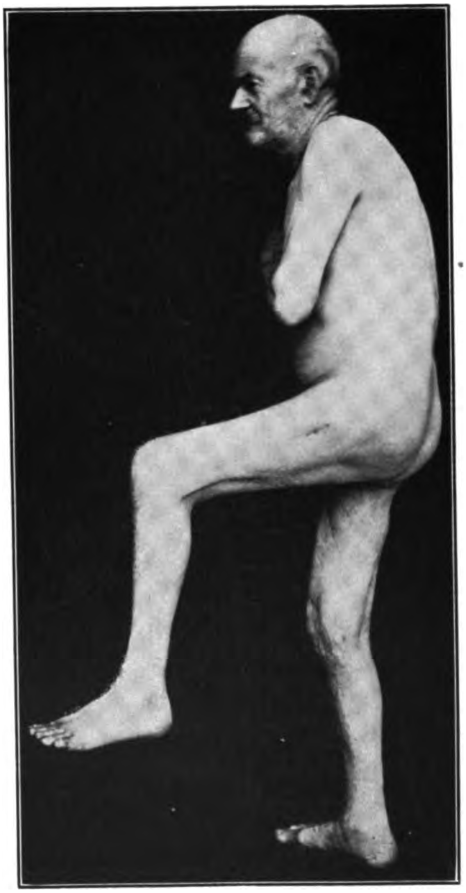


FIG. 83

FIG. 82.—Case No. 9. Photograph, six months after operation, standing erect with both feet together on the floor, in normal voluntary position of rotation of the injured (left) extremity.

FIG. 83.—Case No. 9. Photograph, six months after operation, showing amount of voluntary flexion at the hip-joint.

CASE No. 10.—Fracture of the neck of the right femur.—L. G.; Scotch; janitor; aged fifty-six years; was admitted to Cook County Hospital February 1, 1915, immediately after having fallen on the ice, injuring his right hip.

Examination showed a fat, elderly man, with a helpless right lower extremity. The hip was painful on motion, short 4 cm., and the foot was everted. The röntgenogram showed a fracture of the neck of the right femur with displacement.

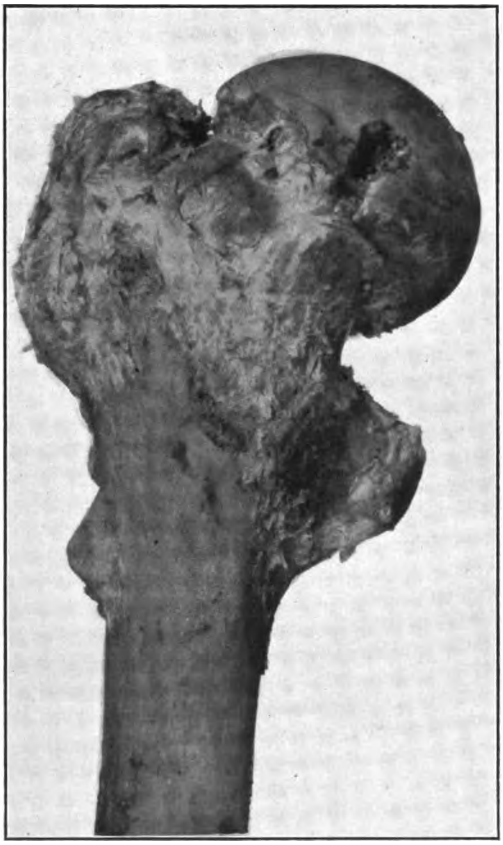


Fig. 84.—Case No. 10. Photograph of pathological specimen of autoplastic repair of fracture of the neck of the femur by a peg transplant, removed twenty-three days after operation. Bony union had resulted at the line of fracture. (Museum of Rush Medical College.)

Operation for the autoplastic repair of the fracture was performed twelve days later with the same technic as Case No. 9. The wound healed by primary union. The patient died twenty-three days after operation.

Through the courtesy of Dr. E. R. LeCount, professor of pathology in Rush Medical College, a postmortem specimen of the upper part of the femur was obtained.

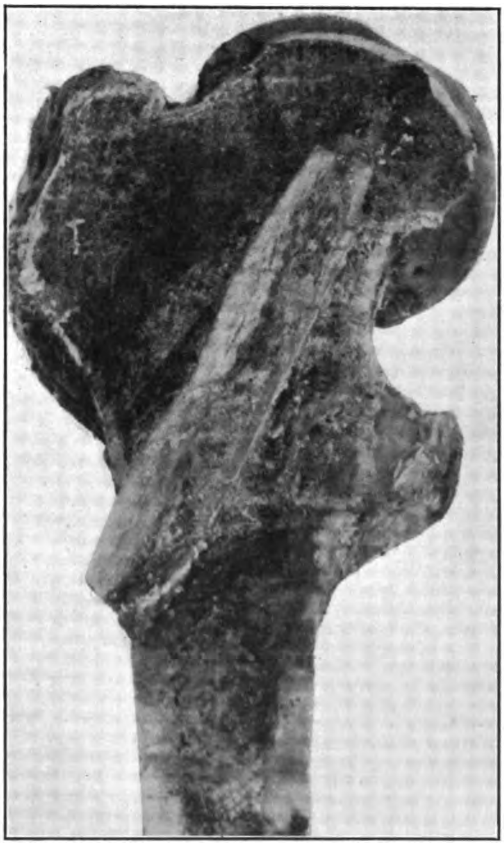


FIG. 85.—Case No. 10. Section of specimen, showing the fibular peg transplant grafted to the surrounding bone and obliteration of the line of fracture. (Museum of Rush Medical College.)

The pathological specimen showed bony union at the line of fracture (Fig. 84). A longitudinal section through the head and neck of the femur and the transplant, showed the following conditions: The transplant was solidly imbedded in the surrounding bone, being substantially attached both to the cortical bone to which it was contacted and to the adjacent cancellous bone of the neck. Radiating from the graft in every direction was a mass of hard bone, infiltrating the cancellous bone and grafting the transplant firmly to its host. The medullary canal of the fibular transplant was sealed at each end by a plug of hard bone, while the remainder of the canal was filled with marrow (Fig. 85).

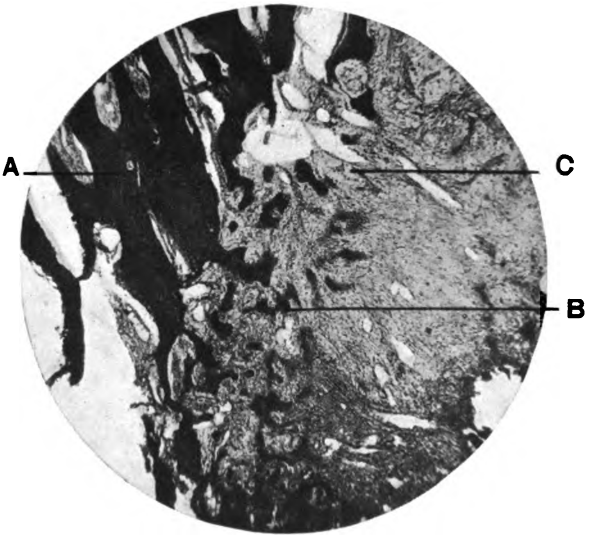


FIG. 86.—Case No. 10. Microscopic section across the grafted area, showing new-formed osseous trabeculæ continuous with the transplant. *A*, transplant; *B*, new osseous trabeculæ; *C*, old osseous trabeculæ.

The line of fracture was obliterated and not discernable on the cut surface of the section of the specimen.

Microscopic examination showed bony union between the fragments at the line of fracture and between the transplant and the fragments (Fig. 86).

The pathological findings in the following case, operated upon by a colleague, are cited, by permission, to illustrate the difference in the local reaction between metal fixation and fixation by autoplastic bone in fractures of the neck of the femur.

The age, location of injury, time of operation after injury, sterility of wound and time of death after operation are sufficiently similar to afford comparison between this and the preceding case.

Case No. 11.—Fracture of the neck of the femur.—C. J.; Swede; laborer; aged fifty-four years; was admitted to Cook County Hospital December 3, 1912, with the history of having fallen from a street car one week previously, injuring his right hip.

Examination showed the usual symptoms of fracture of the neck of the femur with shortening of 4 cm.

Seventeen days after injury an open operation was performed. The fracture was exposed by incision, reduced by mechanical extension, and the fragments fastened together with a metal screw three inches long.

The wound healed by primary union. The patient died twenty-five days after operation.

The pathological specimen showed only fibrous union between the fragments. The screw was loose and movable in the trochanter, which with the fibrous union allowed considerable movement between the fragments (Fig. 87). A röntgenogram of the specimen shows the direction and position of the loose screw (Fig. 88).

2. Fracture of the Greater Trochanter.—When treated by external splints, fibrous union of the fragments in this fracture, as in fracture of the patella and olecranon, is the usual result. Reduction of the trochanter by open operation and direct fixation by an autoplastic peg transplant secures accurate

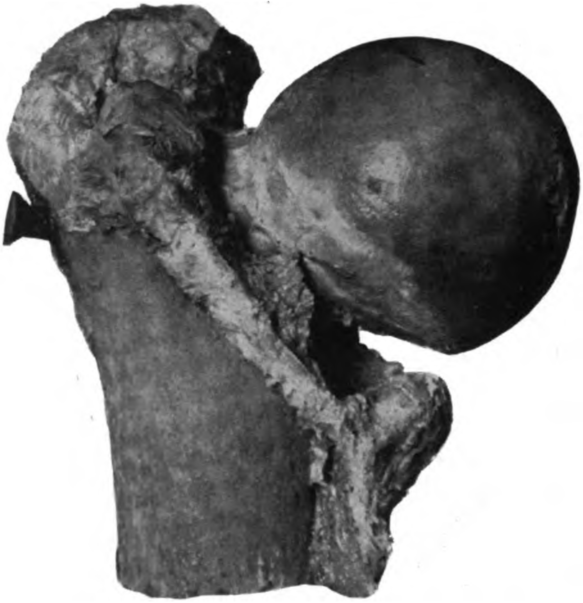


FIG. 87.—Case No. 11. Photograph of pathological specimen of fracture of the neck of the femur, without union, repaired by an iron screw. (Museum of Rush Medical College.)

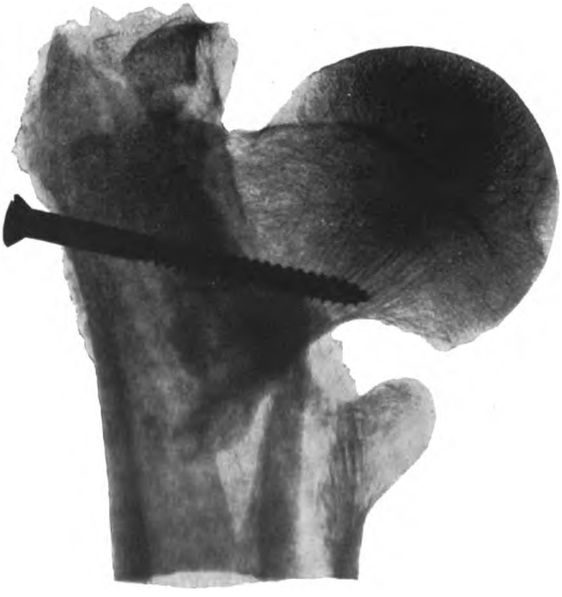


FIG. 88.—Case No. 11. Röntgenogram of the pathological specimen shown in Fig. 87.

apposition and results in bony union. The trochanteric fragment is displaced backward and inward by the traction of the short, powerful muscles connecting it with the pelvis. The action of these muscles must be neutralized by abduction and external rotation of the thigh to prevent muscular spasm and muscular pull on both the fragment and the transplant.

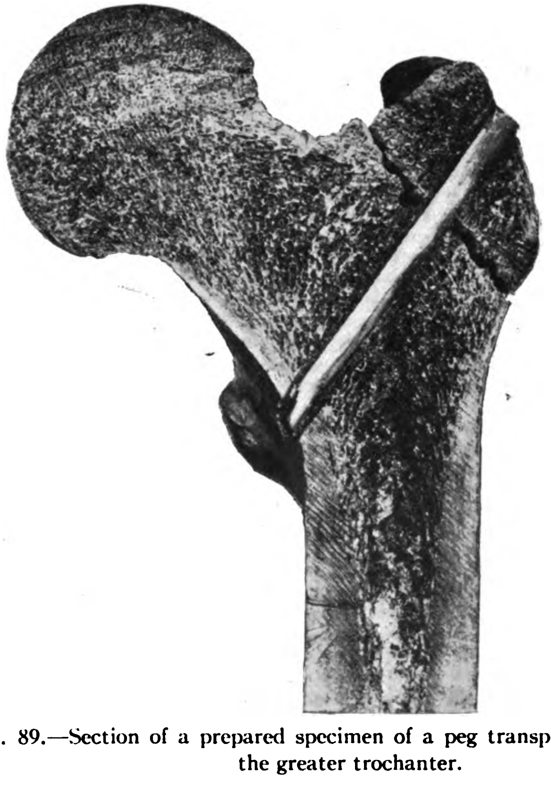


FIG. 89.—Section of a prepared specimen of a peg transplant in fracture of the greater trochanter.

The direction of the autoplastic peg transplant is illustrated by a prepared specimen, sectioned through the trochanter and the transplant (Fig. 89).

In the application of the peg transplant, the fracture is exposed by an incision over the greater trochanter. The interposing clots and fibrous tissue are removed. The small fragment is reduced. A hole is made by a small reamer through the fragment across the femur into compact bone at the base of the lesser trochanter. A slender transplant is removed from the spine of the tibia, long enough to reach through the cancellous bone into the compact bone near the lesser trochanter. It is made quadrilateral in shape, tapering to a point, and large enough to fill the opening in the small fragment, without splitting it. The periosteum is removed. The transplant is driven into the canal, contacting with compact bone at either end and binding the small fragment in position.

The wounds are closed by catgut sutures, in layers, and dressed with gauze. The hip is immobilized in abduction and extreme external rotation by a body plaster-of-Paris cast, extending from the axilla to the toes. The immobilization is retained without change during the period of union of the fracture.

The following personal case illustrates the application of the peg transplant to fractures of the greater trochanter:

CASE No. 12.—Fracture of the greater trochanter.—E. T.; American; janitor; aged fifty years; alcoholic; fell on the street, injuring the right hip. After the injury he was able to walk a short distance with difficulty. He was admitted to Cook County Hospital at once, January 10, 1915.

Examination showed a dissipated old man, suffering from a painful injury to the right hip. There was no deformity, no eversion or abduction or shortening of the lower extremity.

A röntgenogram revealed a fracture of the greater trochanter, with inward and backward displacement of the fragments (Fig. 90).

Operation for autoplastic repair of the fracture was performed one week later. Incision over the greater trochanter exposed the fracture. Extreme abduction and external rotation relaxed the muscles, pulling the small fragment out of position. The small fragment

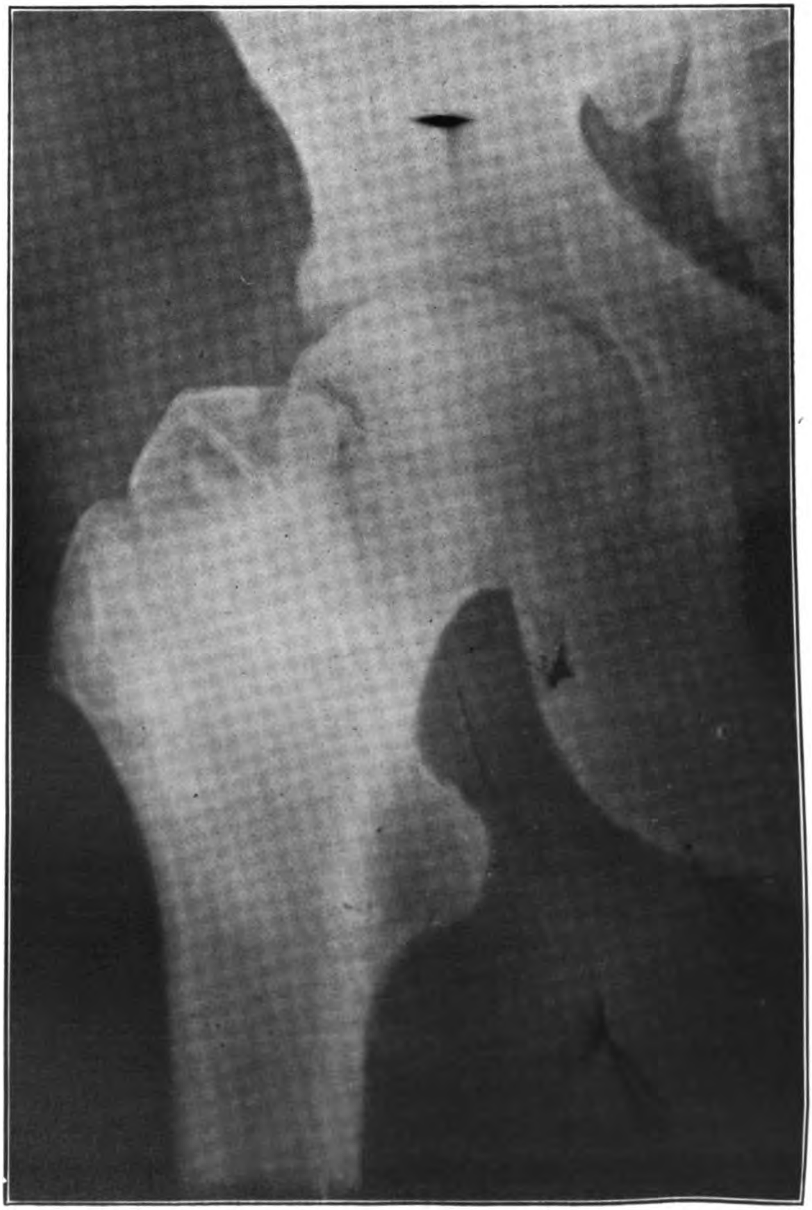


Fig. 90.—Case No. 12. Röntgenogram of fracture of the greater trochanter.

was replaced and a canal cut, with a small reamer, through it and the cancellous bone in the direction of the lesser trochanter.

A peg transplant, cut from the spine of the tibia of the same extremity, of the proper length and size, without its periosteum, was driven through the fragment across the line of fracture through the cancellous bone. It impinged against the compact bone at the base of the lesser trochanter, binding the fragment into place.

The wounds were closed in layers by catgut sutures, dressed with sterile gauze and the extremity immobilized in abduction and extreme external rotation by a body plaster-of-Paris cast extending from the ribs to the toes.

A röntgenogram, taken eight weeks after operation, shows the end of the transplant and the trochanter surrounded by callus (Fig. 91).

The patient recovered with good functional abduction and rotation of the thigh.

3. INTERTROCHANTERIC FRACTURE OF THE FEMUR.—Both fragments are drawn entirely out of alignment and rotation by the muscular attachments in this fracture. There is no method of external reduction or immobilization which will give either anatomical or functional results.

Autoplastic fixation of intertrochanteric fractures is illustrated by a section of a prepared specimen showing a peg transplant bridging the line of fracture and holding the fragments in alignment (Fig. 92).

Operative access to the fracture is gained by an incision at the outer part of the hip from the greater trochanter downward over the line of fracture. The upper fragment is grasped and held by a Lowman clamp, while a canal is cut, with a large hand reamer, upward through the cancellous bone of the trochanteric region. It extends entirely through the upper fragment, in the axis of the medullary canal of the

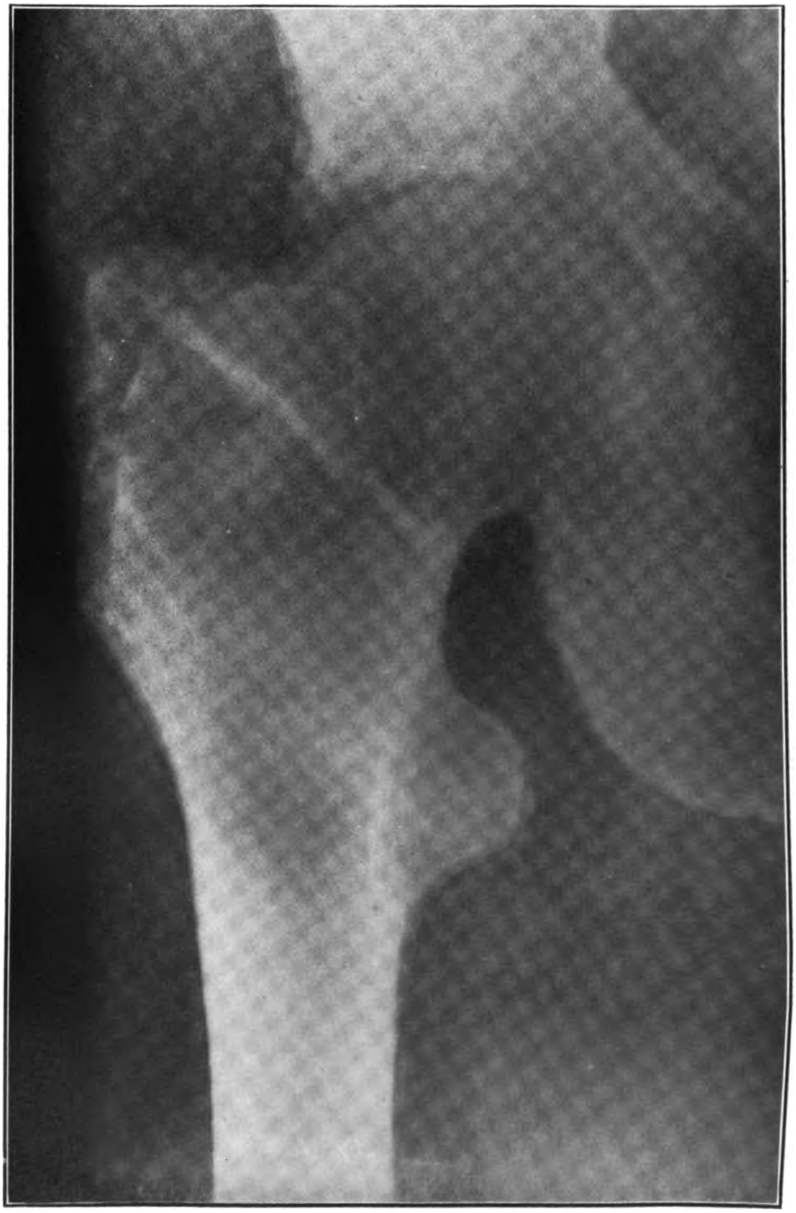


FIG. 91.—Case No. 12. Röntgenogram of autoplastic repair of fracture of the greater trochanter by peg transplant, eight weeks after operation.

shaft of the femur. The medullary canal of the upper end of the lower fragment can be shaped with the same reamer if necessary. A peg transplant is taken from the crest of the tibia of the same extremity without periosteum. It is calipered to the size of the reamer. It is made long enough to pass through the small fragment and to enter the medullary canal of

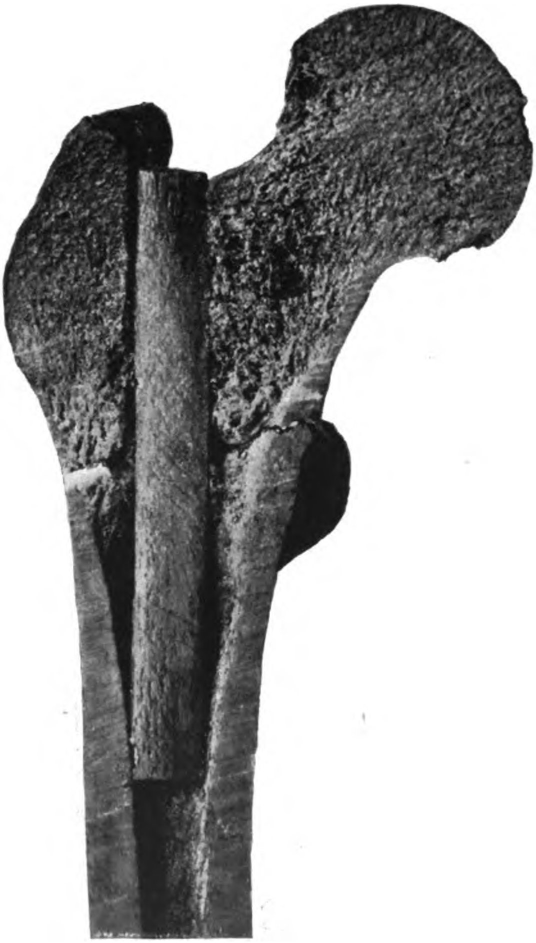


FIG. 92.—Section of prepared specimen of a peg transplant in an intertrochanteric fracture of the femur.

the lower fragment a sufficient distance to give stability to the reduction. It is driven into the canal in the upper fragment from below until its lower end is flush with the lower end of the fragment and its upper end extends through the fragment between the muscles attached to the greater trochanter. The fracture is reduced and the transplant is driven downward across the line of fracture into the medullary canal of the upper end of the lower fragment.

The wound is closed, dressed and the extremity immobilized by a body plaster-of-Paris cast (Fig. 78). The thigh is well abducted and rotated outward to relax the muscles attached to the greater trochanter. The leg and thigh are slightly flexed to prevent muscular spasm and consequently movement of the transplant, which will prevent its grafting to the surrounding bone. The cast is not removed during convalescence.

The personal case described below gives the course and result in an intertrochanteric fracture of the femur accompanied by extensive displacement and rotation of the fragments.

CASE NO. 13.—Intertrochanteric fracture of the femur.—M. B.; Pole; laborer; aged twenty-two years; was admitted to the University Hospital March 10, 1914, immediately after injury produced by falling down an elevator shaft.

Examination showed a vigorous young man with a helpless right lower extremity. The hip was prominent, the limb was 3 cm. short and in external rotation. A röntgenogram revealed a transverse fracture of the femur immediately above the lesser trochanter (Fig. 93). The deformity could not be reduced by traction, manipulation and position.

An open operation for reduction and autoplastic bone transplantation was performed eight days after injury. Incision over the fracture showed that the upper fragment was rotated and drawn out of position

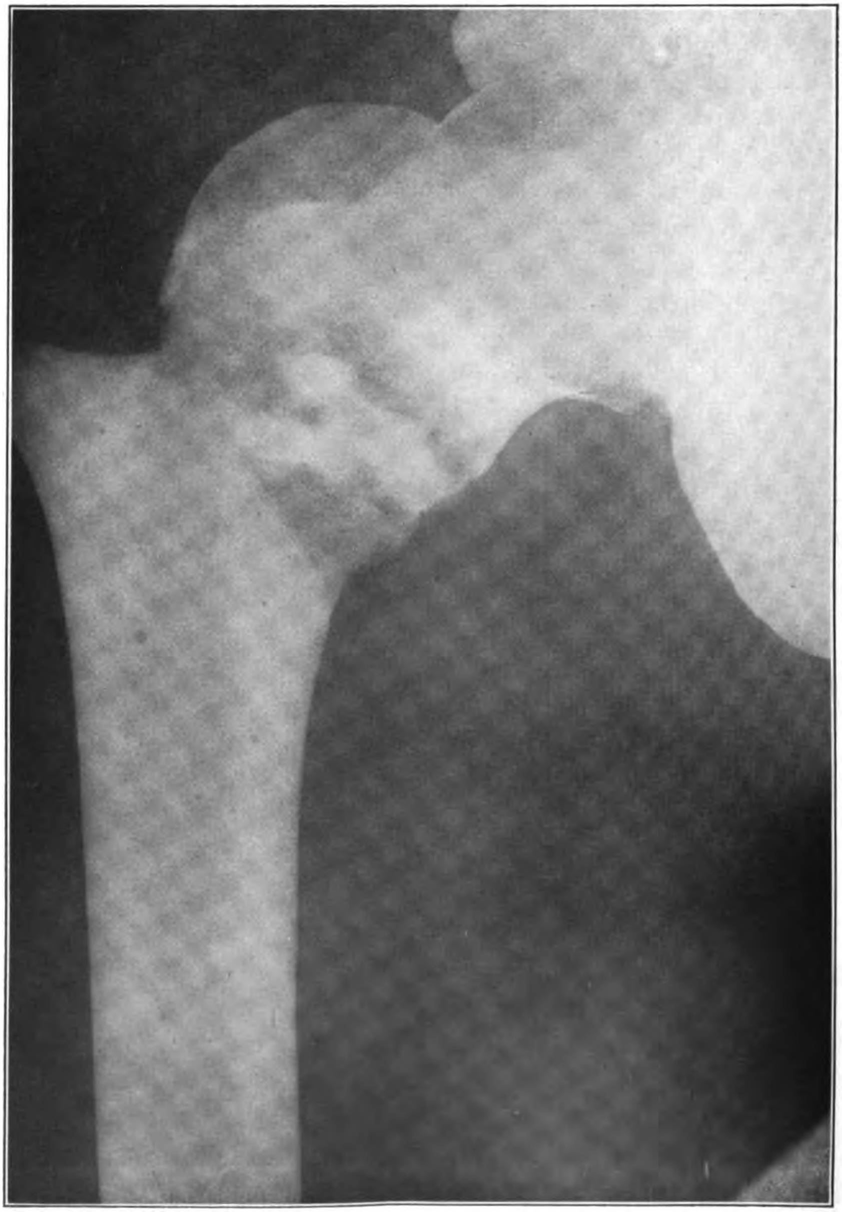


FIG. 93.—Case No. 13. Röntgenogram of intertrochanteric fracture of the femur.

by the muscles attached to the greater trochanter. The upper fragment pointed downward, outward and backward. The lower fragment was drawn up, overlapping the small fragment. The small fragment was held by a clamp while a canal was cut in the axis of the shaft of the femur and a peg transplant fitted and driven into it. The projecting end of the transplant was manipulated into the medullary canal of the lower fragment (Fig. 94). The transplant, 8 cm. long, without its periosteum, was taken from the crest of the tibia of the same leg.

The wounds were closed by sutures in layers and the whole extremity immobilized in slight abduction by a body plaster-of-Paris cast for twelve weeks.

Six months after operation the patient was walking without the use of a cane or other support.

A röntgenogram, taken thirteen months after operation, shows bony union of the fragments. The interior of the intertrochanteric region around the transplant was filled with new bone of a density sufficient to very nearly obscure the peg transplant. A röntgenogram, taken sixteen months after operation, shows the new bone rapidly becoming cancellous in structure and the peg transplant very nearly absorbed (Fig. 95).

4. SUBTROCHANTERIC FRACTURE OF THE FEMUR.—It is impossible to correct the deformity of flexion and abduction of the upper fragment by external means. It is very difficult to correct the adduction and shortening of the lower fragment by position and traction or by external splints. Open reduction with internal fixation of the fragments in their correct alignment and rotation is the only possible means of obtaining good results. The use of the peg transplant furnishes the best method of securing good anatomical and functional end-results.

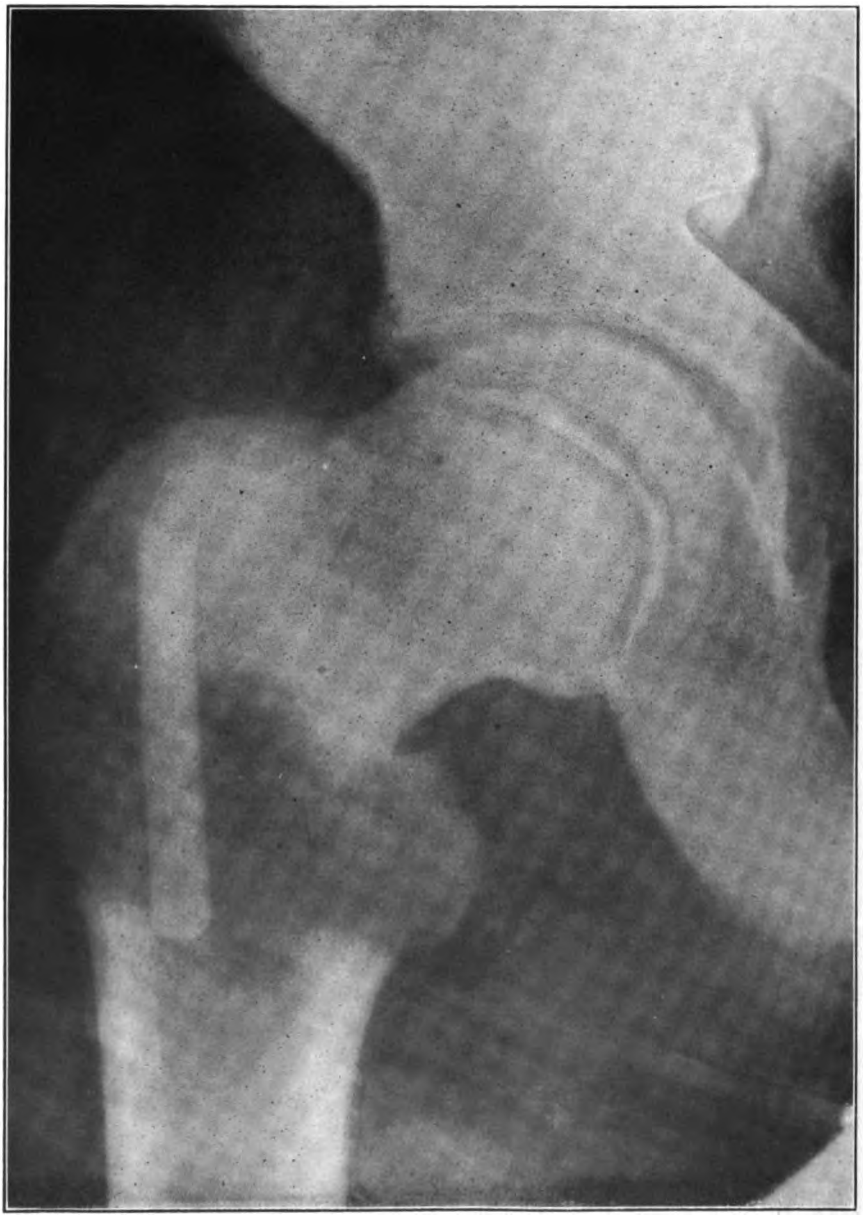


FIG. 94.—Case No. 13. Röntgenogram, of repair of intertrochanteric fracture of the femur by a peg transplant.

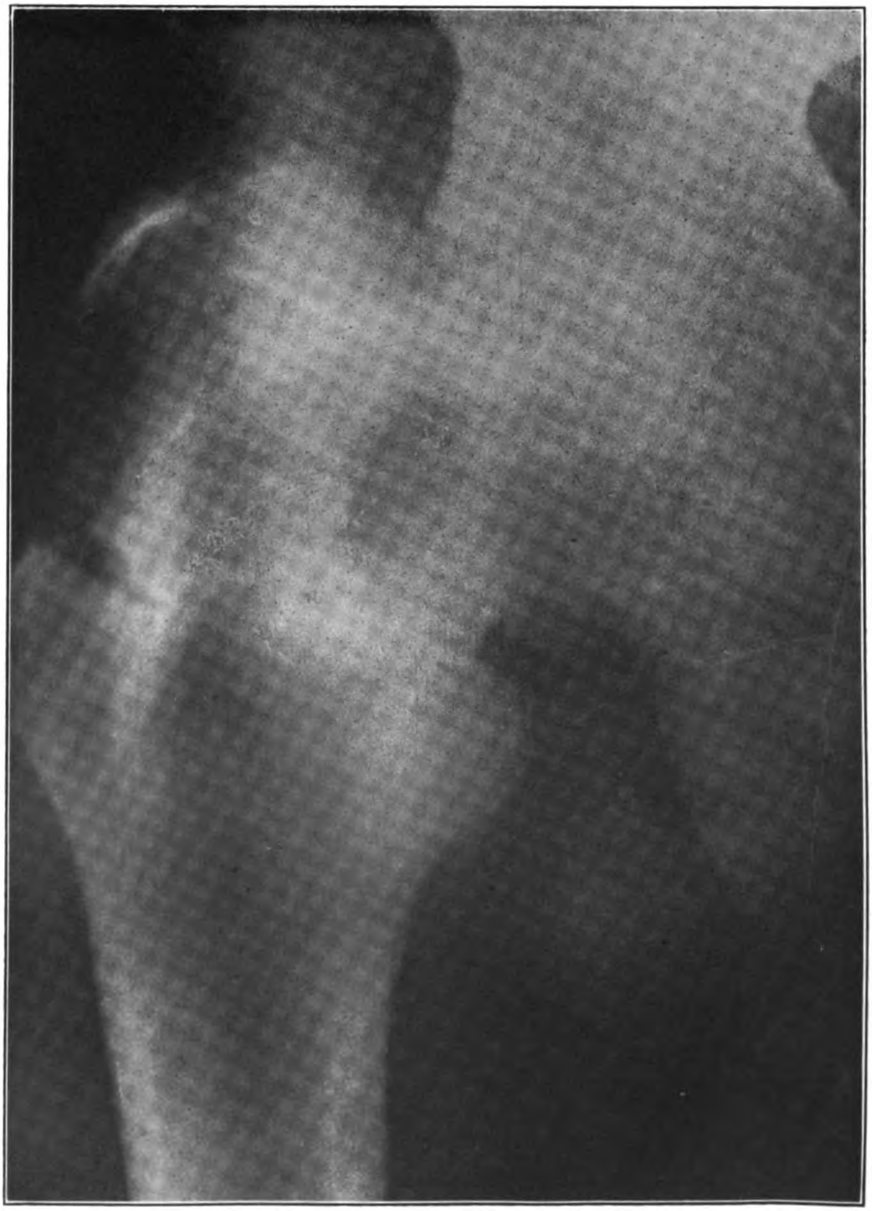


FIG. 95.—Case No. 13. Röntgenogram, sixteen months after operation, showing the intertrochanteric area filled with compact bone and almost complete absorption of the transplant.

The prepared specimen illustrates the application of the peg transplant to this fracture (Fig. 96).

The operative procedure for reduction of subtrochanteric fractures of the femur and fixation by the peg transplant is exactly the same as that employed in intertrochanteric fractures, except that the transplant must be considerably longer to reach across the line of fracture into the medullary canal of the lower fragment.

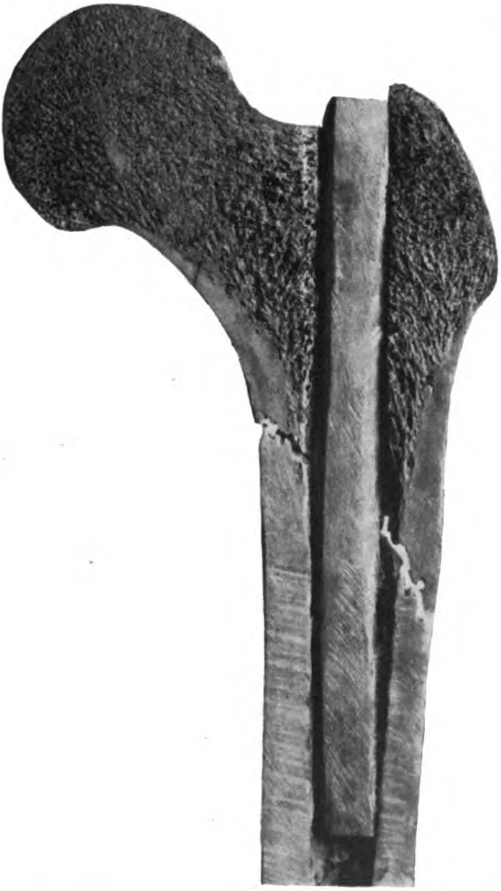


FIG. 96.—Section of a prepared specimen of medullary transplant in subtrochanteric fracture of the femur.

The position of immobilization in the body cast is important. The thigh is abducted until checked by the head of the femur against the acetabulum and the extremity rotated outward to relax the muscles attached to the greater trochanter. The thigh is slightly flexed to relax the iliopsoas muscle and the leg is flexed until the hamstrings are slack. If these details of position are not carried out, there will be intermittent muscular spasm and muscular traction on the fragments which will cause movement between the transplant and its host, preventing grafting to the fragments. If muscular spasm and traction are active, the hard bony transplant may cut into the soft, cancellous bone of the upper fragment and distort the alignment.

5. FRACTURE OF THE SHAFT OF THE FEMUR.—The middle of the shaft of the femur is composed of thick, dense bone, with a small medullary canal. The thickness of the wall is usually about the same as the diameter of the medullary canal at that location.

Fractures near the middle of the shaft are usually oblique. The deformity is due to a persistent overriding of the fragments. Reduction cannot be continuously maintained by traction on the leg and external splints. The use of the medullary transplant is indicated in the treatment of fractures of the shaft of the femur, unless there are irregularities of the ends of the fractured bone which will hold the reduction in alignment without overriding and shortening.

A section of a prepared specimen of the femur and transplant shows its application to fractures of the middle of the shaft (Fig. 97).

For the operation, a longitudinal incision is made along the outer part of the thigh at a level that will expose the line of fracture. The ends of the fracture are turned out of the wound by bending the thigh.

The wound is cleared of clots and detritus. The fracture is examined as to comminution and shape of the ends of the fragments. The length and size of the material required for the transplant is estimated by measurement of the obliquity of the fracture and by measurement of the size of the medullary canal by calipers. , The medullary transplant is cut according to accurate measurements, from the crest of the tibia of the same leg, without periosteum. One end of it is fitted closely to the medullary canal of the lower fragment. The other end is fitted loosely to the lower end of the upper fragment. The transplant is next driven snugly, the proper distance, into the lower fragment. By traction and manipulation of the extremity, the projecting end of the transplant is slipped into the canal fitted for it in the upper fragment. As the extremity is straightened the muscles of the thigh contract and pull the ends firmly together aligning the fragments over the transplant. The wounds are closed in the usual

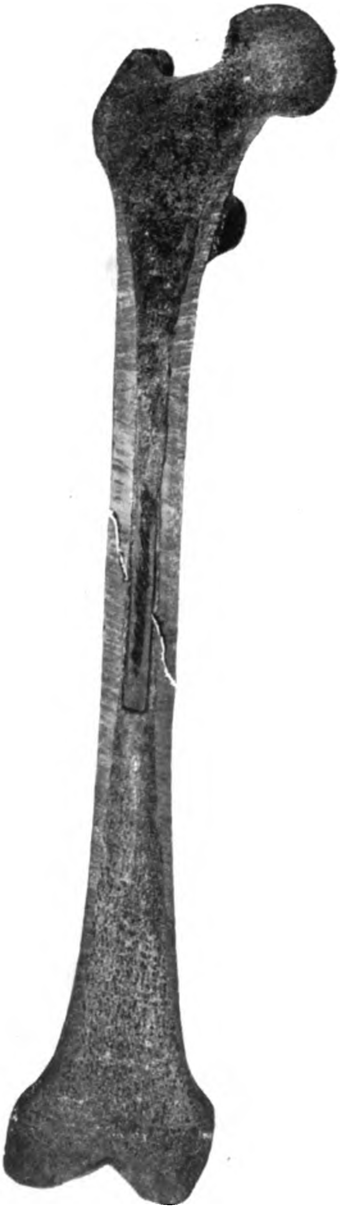


FIG. 97.—Section of a prepared specimen of a medullary transplant in fracture of the shaft of the femur.

manner and the extremity immobilized in a plaster-of-Paris body cast to remain during convalescence.

The history of the following case, referred to the author through the courtesy of Dr. F. A. Besley, describes a case of fracture of the middle of the shaft of the femur.

CASE No. 14.—Fracture of the shaft of the femur.—R. B.; Russian Jewess; housewife; aged sixty-three years; was admitted to Cook County Hospital February 26, 1914, following the injury. While doing housework the patient slipped on the floor and fell, striking her knee, producing a fracture of the thigh.

Examination, four days later, showed a frail, poorly nourished, emaciated old woman, suffering from decubitus and pulmonary congestion. A röntgenogram revealed a transverse fracture of the shaft of the right femur, with much overlapping of fragments (Fig. 98).

Operation for fixation by an autoplastic medullary transplant was performed March 3, 1914. With the usual technic a transplant 8 cm. long and 1.2 cm. wide, without periosteum, was removed from the tibia of the same extremity and placed at the defect in the medullary canal of the femur. Because of the precarious condition of the patient, spinal anesthesia was used. A rapid transfer of the transplant was made without appreciable shock. The wounds were closed in layers by catgut sutures, dressed with sterile gauze and the fracture immobilized by a body plaster-of-Paris cast. The patient was put to bed in the Fowler position and quickly recovered from her pulmonary complications.

A röntgenogram taken after the cast was removed shows good alignment with the transplant in the medullary canal across the line of fracture grafted to both fragments (Fig. 99).

6. SUPRACONDYLOID FRACTURE OF THE FEMUR.—Fractures in this location are usually transverse and

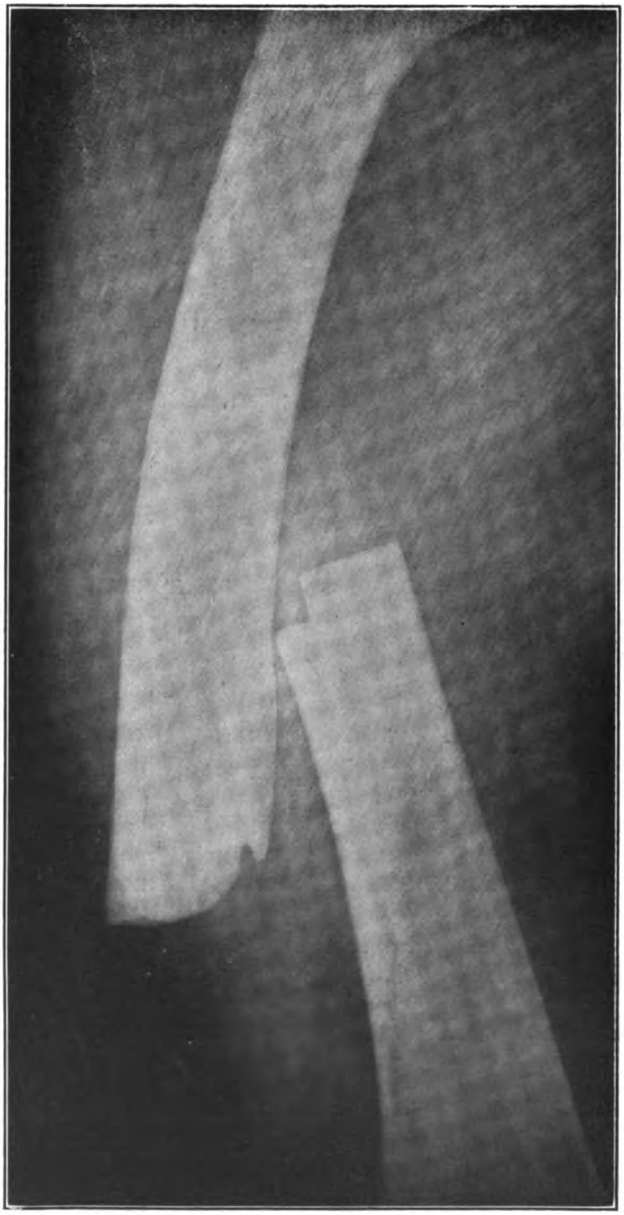


FIG. 98.—Case No. 14. Röntgenogram of fracture of the shaft of the femur.

can be reduced and immobilized by external methods, but they are occasionally oblique or spiral and must

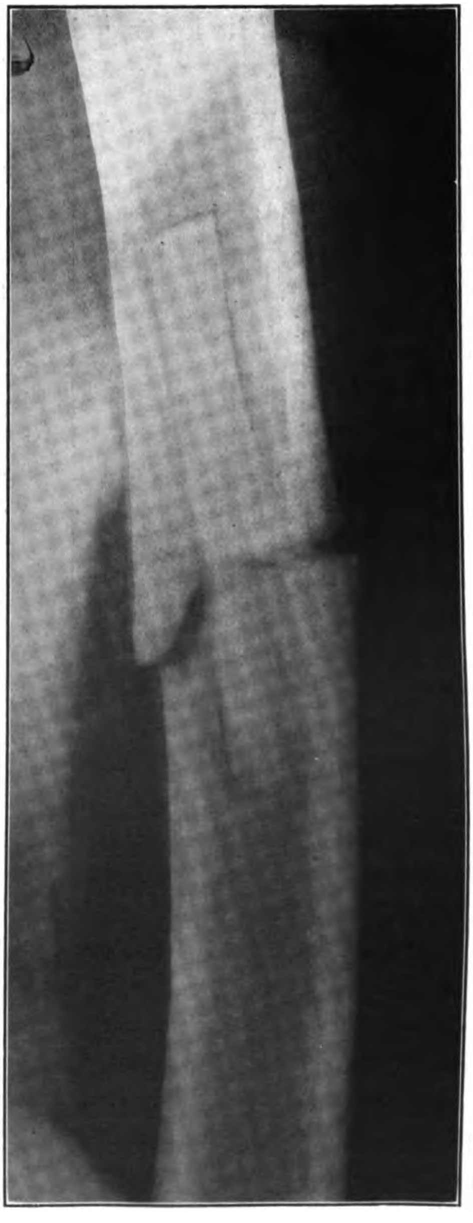


FIG. 99.—Case No. 14. Röntgenogram of autoplastic repair of fracture of the shaft of the femur by a medullary transplant.

be subjected to open reduction and local fixation. Oblique or spiral fractures above the condyles can be secured by large peg transplants.

The medullary canal at its lower end is large and the cancellous bone above the condyles is soft, requiring very little fitting for the peg. A thick transplant having been secured from the tibia or fibula of the same side, without periosteum, of a length necessary to support the fragments in alignment, is fitted to both fragments and driven into the cancellous bone of the lower fragment. A steel drill is temporarily passed from side to side through the lower fragment at the end of the transplant to prevent it from being forced too far into the lower fragment during subsequent manipulations. It is withdrawn before the wound is closed. The lower extremity is manipulated so that the projecting end of the transplant enters the medullary canal of the upper fragment. The wound is closed and the extremity held in alignment and enveloped in a body plaster cast which remains during convalescence.

7. FRACTURE OF THE CONDYLES OF THE FEMUR.—In fractures of either the outer or the inner condyle, the fragment may impinge upon the articulation, endangering the free movements of the knee-joint, after the best external reduction that can be obtained. When this occurs the fragment should be fastened to the femur by a peg transplant of which the plan of application is illustrated by a prepared section through the condyles (Fig. 100).

Incision is made over the injured condyle exposing the fracture. The fragment is replaced and a drill passed through it upward, at a binding angle, through the cancellous bone of the lower end of the femur, into the compact bone on the opposite side.

A thin, rectangular, tapering transplant is sawed from the crest of the tibia of the same extremity, without its periosteum. It is made large enough in size to bind in the hole made by the drill. The transplant is sharply driven into position, binding the condylar fragment to the femur.

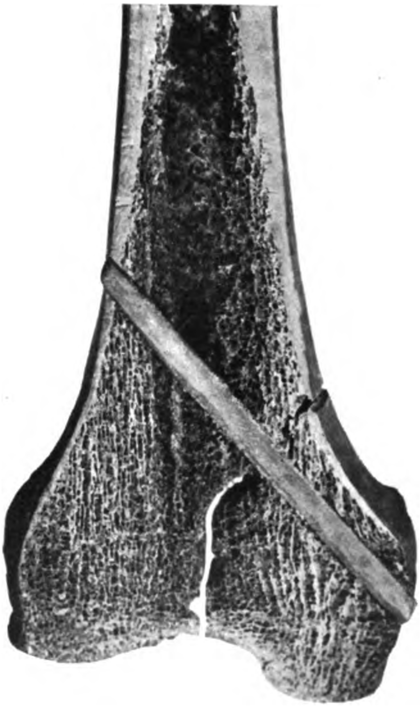


FIG. 100

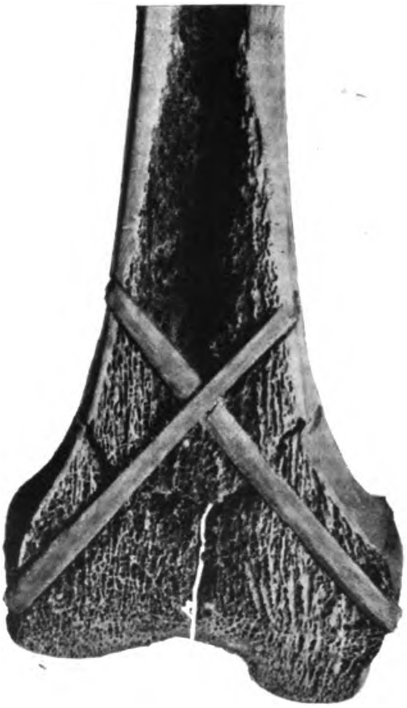


FIG. 101

FIG. 100.—Section of prepared specimen of a peg transplant in the fracture of the condyle of the femur.

FIG. 101.—Section of prepared specimen of double-peg transplant in fracture of both condyles of the femur.

When both the external and internal condyles are fractured at the same time, two transplants can be used, crossing each other in the cancellous bone of the lower end of the femur (Fig. 101).

After closing the wound, the extremity is fixed by plaster of Paris with the leg in semiflexion.

FRACTURES OF THE TIBIA.

SPECIAL ANATOMY.—A longitudinal section through the tibia shows the relation of the shaft to the medullary canal filled with marrow and the cancellous bone at the expanded ends (Fig. 102). The anterior border or crest of the tibia is composed of very dense, hard, compact bone, which reaches its greatest density at about the junction of the middle and lower thirds, a point where fractures frequently occur. The thickness of the crest modifies the shape of the medullary canal, making it more triangular than circular where the tibial crest is thickest. The upper and lower parts of the tibia consist of an expanded mass of cancellous bone covered by a thin, expanded layer of compact bone.

1. FRACTURE OF THE SHAFT OF THE TIBIA.—Spiral fractures of the shaft occur much more frequently than the literature would indicate. They are very difficult to retain in reduction because of the shape of the ends of the fragments. When reduction of fractures of the shaft of the tibia cannot be maintained by external splints, the medullary transplant is indicated.

The prepared section shows the plan of application of the medullary transplant to fractures of the shaft of the tibia (Fig. 103).

A curved incision is made over the shin indirectly exposing the fracture. If there is a fracture of the fibula at about the same level, reduction is easily accomplished. If the fibula is fractured at a different level, especially if the fragments are impacted, reduction cannot usually be accomplished without surgical fracture of the fibula at a point opposite the fracture in the tibia.

The detritus produced by the injury is cleared from the wound and the fragments are prepared for the transplant. Careful measurements for the transplant

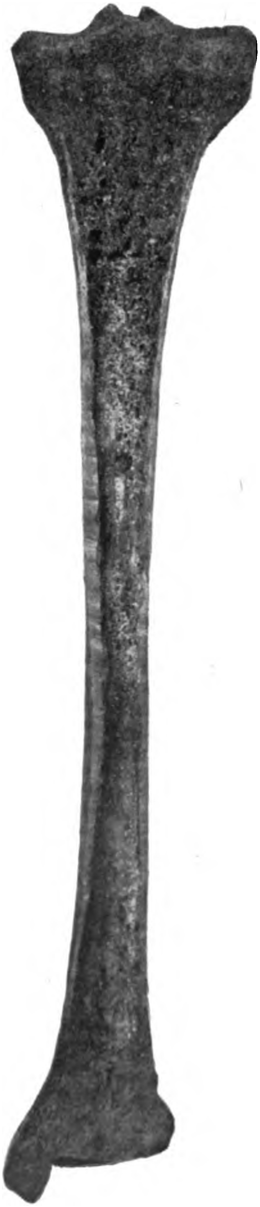


FIG. 102.—Section through the tibia, showing the medullary canal and the arrangement of the cancellous bone.

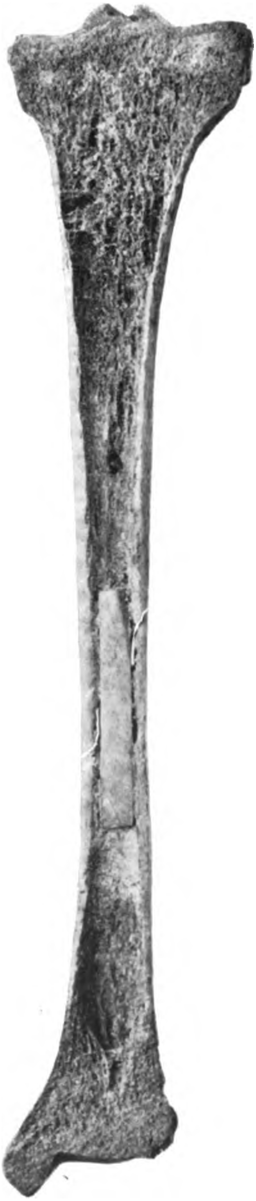


FIG. 103.—Section of a prepared specimen of a medullary transplant in the shaft of the tibia.

are made. It should be shaped to fit into the irregularities of the medullary canal so that it will act like a key to prevent rotation of the fragments when they are brought together. The transplant can be obtained from the crest of the tibia, preferably from the same leg, when there is room at a distance from the fracture, or from one of the fragments of the fibula, as the judgment of the surgeon dictates in the individual condition. A section of fibula usually will fit the irregular shape of the medullary canal of the tibia at the point of fracture and its shape will prevent rotation of the fragments.

The transplant is fitted to the irregularities of the upper fragment, so that it will slip in and out. This is done by scraping the interior of the shaft with a bone curette or with a small electric burr. If the transplant is dowelled or the medullary canal is reamed until it is circular, the spiral fragments of the tibia will rotate before a plaster cast can be applied and the accuracy of the reduction will be lost.

The other end of the transplant is fitted and driven snugly into the lower fragment. The projecting end is manipulated into the prepared upper fragment and the leg is straightened. The muscles of the leg immediately contract and bring the fragments firmly together in alignment over the transplant.

The wound is closed, dressed, and the leg fixed in plaster, the immobilization to remain undisturbed during convalescence.

In the following histories of personal cases, material for the transplant was obtained from the spine of the tibia in the first and second cases, from one of the fragments of the fibula in the third case, acting in a satisfactory manner in each case.

CASE No. 15.—Fracture of tibia and fibula.—L. K.; American; laborer; aged thirty-three years;

was admitted to Cook County Hospital January 10, 1914, immediately following the injury. While intoxicated, the patient slipped on the ice-covered sidewalk and fell, breaking his left leg. A röntgenogram showed a rather long, spiral fracture of the lower third of the tibia, with about 2 cm. of overriding, and complete displacement of the fragments. It was accompanied by a slivered and impacted fracture of the upper third of the fibula.

The patient developed an attack of delirium tremens, during which the leg was treated with applications of ice in a fracture box. After recovery from the delirium tremens, an attempt at reduction and immobilization in a circular plaster cast was made, under complete ether anesthesia. Following this attempt a röntgenogram (Fig. 104) showed that the efforts at reduction had not changed the position of the fragments, as shown by comparison with the original röntgenogram, evidently due to impaction of the fragments of the fibula.

Open operation was performed on January 24, 1914. Incision over the shin showed an overriding displaced, spiral fracture of the tibia. It could not be reduced by direct manipulation and extension, or by manipulation of the fragments with levers in the open wound, on account of a coexisting fracture of the fibula at a higher level.

A transverse fracture of the fibula was made with a chisel from the outside, opposite the fracture in the tibia. This allowed reduction of the fragments of the tibia, but because of the spiral shape of the fracture and traction of the muscles attached to the lower fragment it was impossible to immobilize the fragments and retain them in reduction.

To overcome the tendency to displacement, a medullary transplant was inserted across the line of fracture.

shows good alignment of the fragments with bony union of the fracture (Fig. 108).

A good functional recovery has resulted.

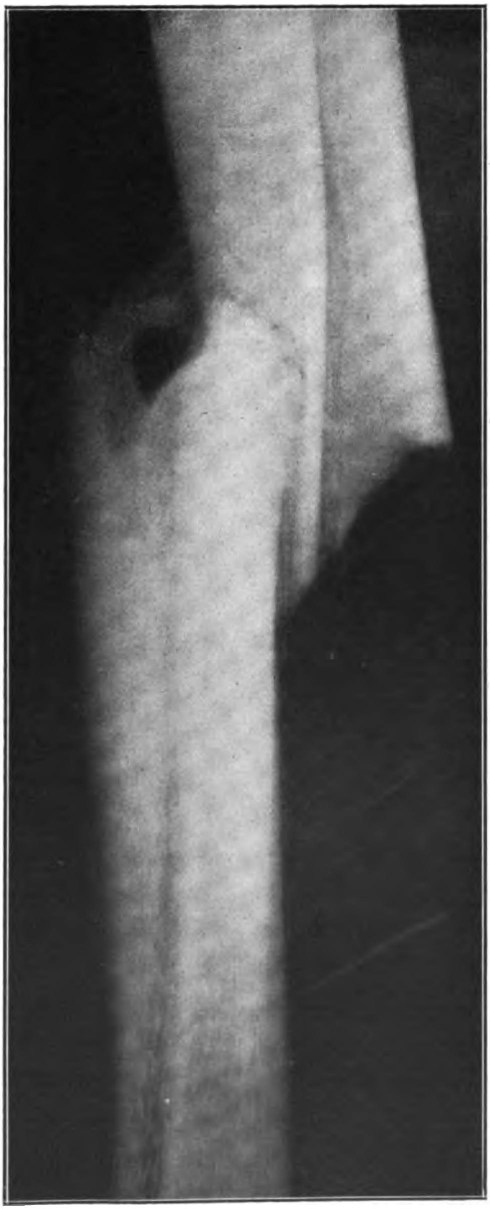


FIG. 107.—Case No. 16. Röntgenogram of fracture of the tibia and fibula.

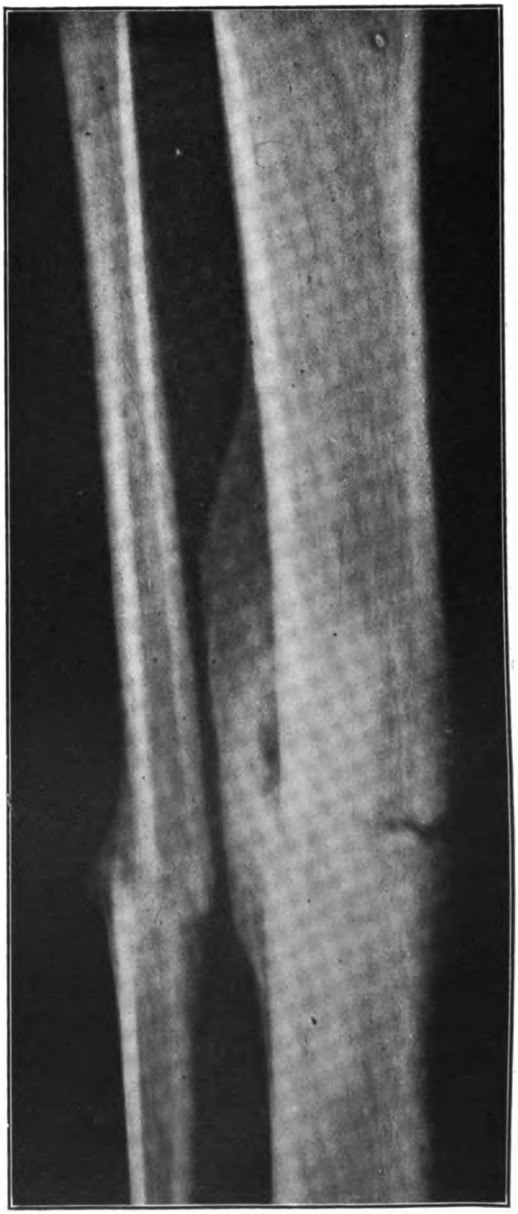


FIG. 108.—Case No. 16. Röntgenogram of autoplastic repair of fracture of the tibia by a medullary transplant, four months after operation, showing bony union of the fracture with substantial callus.

Case No. 17.—Fracture of tibia and fibula.—F. M.; Irish; school-boy; aged fourteen years; was admitted to the University Hospital September 21, 1914, with his left leg in a plaster cast. He was injured in a runaway by collision with a telegraph pole three weeks previous to admission. He was taken to Cook County Hospital, where three unsuccessful efforts at reduction, under ether anesthesia, were made during the time that he was in the hospital. Rather than submit to open operation, he left the hospital.

Examination showed a healthy, vigorous boy, with his left leg in a cast. A röntgenogram revealed fractures of both bones in the lower third of the leg, with the fragments out of alignment (Fig. 109).

Operation for reduction and autoplastic repair of the fracture of the tibia was performed two days later. The fracture was exposed by direct incision and the position and condition of the fragments examined. Another incision on the outside of the leg exposed the fracture in the fibula. A section of the upper fragment of the fibula 6 cm. in length was removed, without periosteum, for the transplant.

The oval shape of the fibula at this section corresponded very closely to the shape and size of the medullary canal of the tibia. When it was fitted and introduced as a medullary transplant, it locked the fragments of the tibia in a very firm and substantial manner. The wound was closed in layers by catgut sutures and covered by gauze dressings. The leg was immobilized by a circular plaster-of-Paris cast.

A röntgenogram, taken two weeks after the operation, shows the fibular transplant across the line of fracture, with good alignment of the fragments of the tibia (Fig. 110).

The wound was dressed for the first time three weeks later, when the fracture seemed firm and solid.

The patient left the hospital on crutches with the leg protected by a light plaster-of-Paris cast.

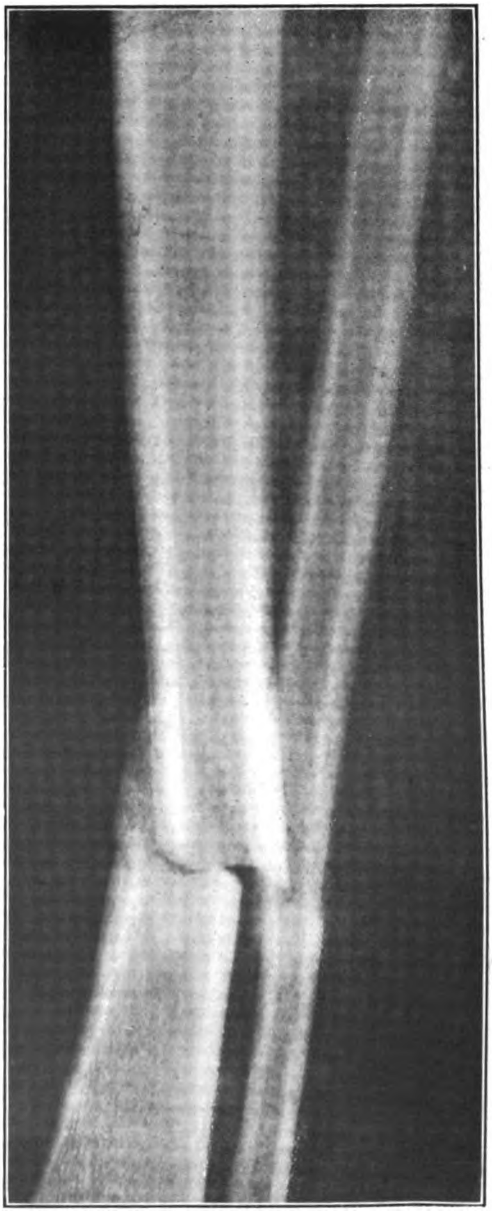


FIG. 109.—Case No. 17. Röntgenogram of fracture of tibia and fibula.

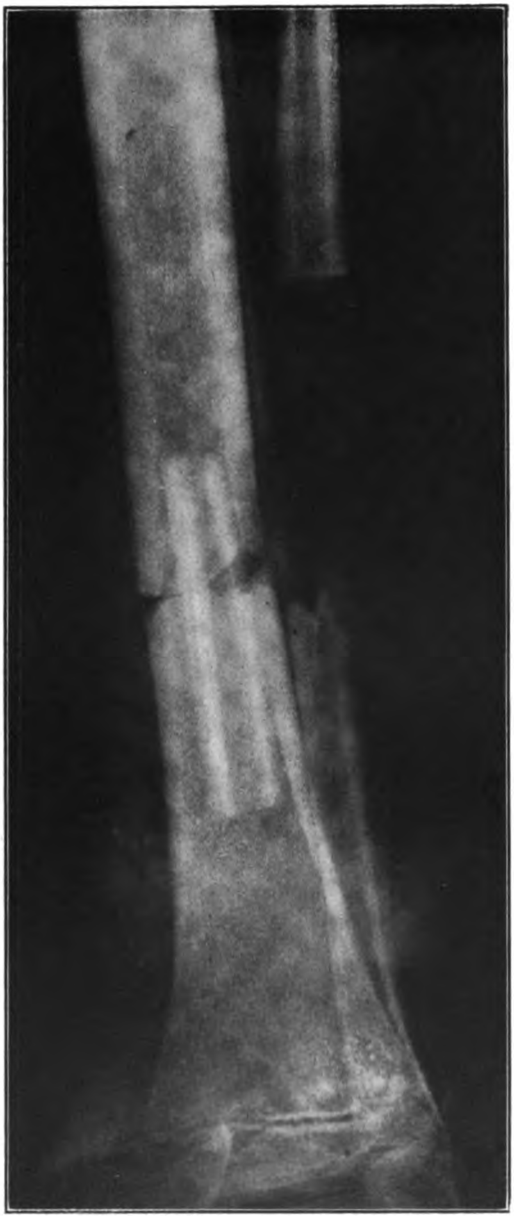


FIG. 110.—Case No. 17. Röntgenogram of autoplastic repair of fracture of the tibia by a medullary transplant taken from the fibula of the same leg, two weeks after operation, showing the fragments in alignment and beginning regeneration of bone at the defect in the fibula.

A röntgenogram, taken two months after the operation, shows union of the fracture, the transplant grafted to the fragments, and beginning regeneration of bone at the defect in the fibula. The ends of the medullary canal in the transplant are sealed by new bone (Fig. 111). A röntgenogram, taken eleven months after operation, shows bony union of the fragments of the tibia, with beginning absorption of the transplant, especially at the lower end. There is also beginning reëstablishment of the medullary canal of the tibia through the medullary canal of the transplant. Regeneration at the defect in the fibula exhibits a solid bony replacement in which a new medullary canal is beginning to appear in the upper part where previous röntgenograms showed the earliest efforts at regeneration (Fig. 112).

Good anatomical and functional recovery has resulted.

The inlay transplant may be used as a method of internal fixation in fractures of the shaft of the tibia where there is displacement of the fragments which cannot be retained in reduction without internal fixation and where the fibula is not broken. There must be sufficient space on either side of the fracture to make the gutter and to obtain the required length of bone for the transplant.

2. FRACTURE OF THE INTERNAL MALLEOLUS.—Where there is a fracture of the internal malleolus with displacement to such an extent that the mortise of the joint is spread or where the fragment impinges upon the articulation in a manner which checks free motion, the malleolus should be fastened to the tibia in its normal relation to the bone and the ankle-joint by a peg transplant. It mechanically holds the fragment in position until grafting of the transplant and union of the fracture occur.

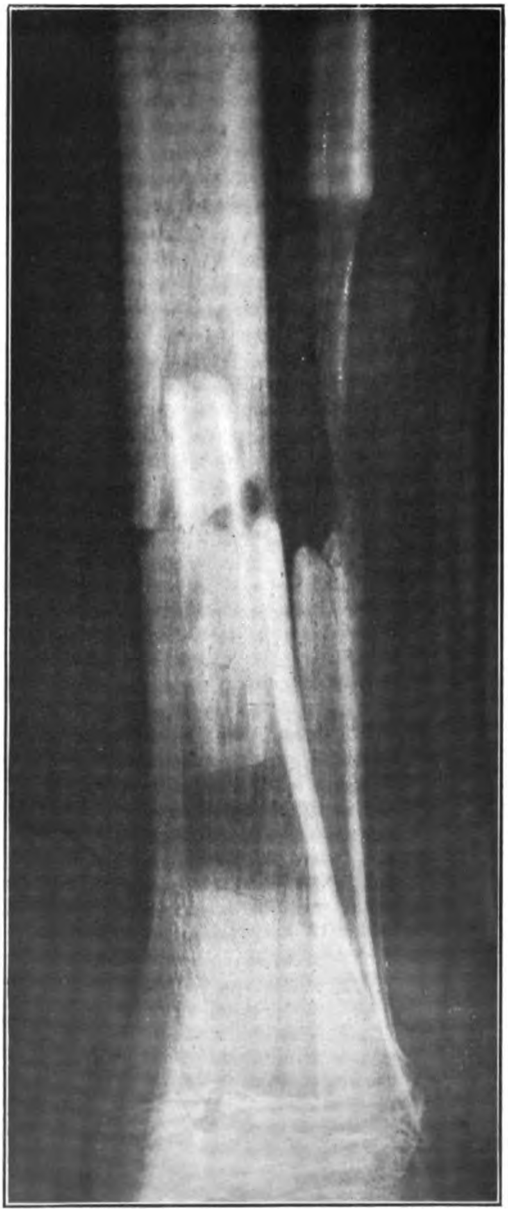


FIG. 111.—Case No. 17. Röntgenogram, two months after operation, showing the transplant grafted to the fragments with bony union at the fracture. Regeneration of bone at the defect in the fibula is progressing rapidly.

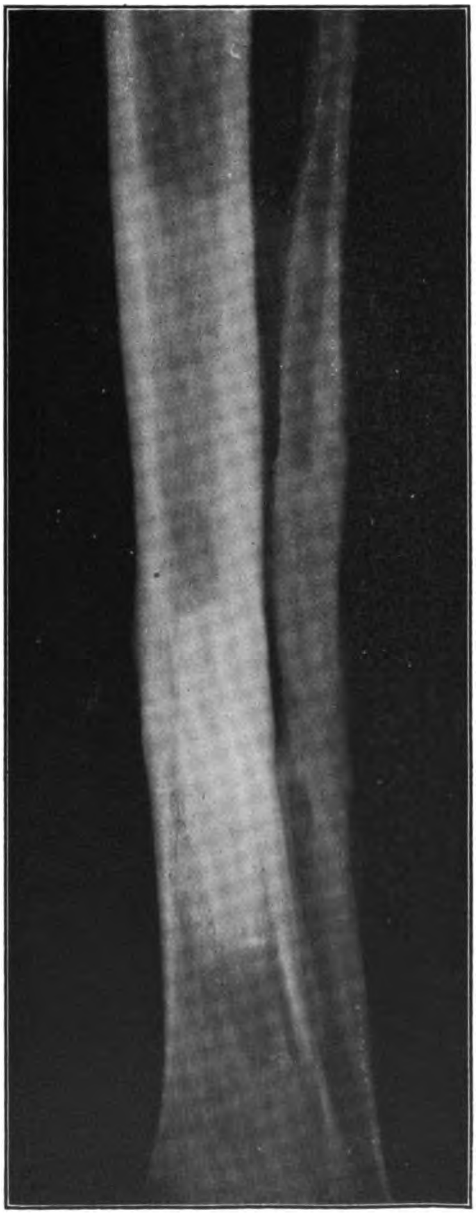


FIG. 112.—Case No. 17. Röntgenogram, eleven months after operation, showing complete bony repair of the fracture in the tibia, with beginning absorption of the transplant and solid bony regeneration at the defect in the fibula.

The prepared section of the malleolus shows a peg transplant holding the fragment to the tibia (Fig. 113). An operative incision is made on the inner side of the ankle exposing the malleolus. The fragment is replaced and held while a drill is passed through the fragment into the tibia, through the cancellous bone of the interior and into the compact bone of the outer side. A rectangular transplant is cut from the spine of the tibia of the necessary size and thickness, without

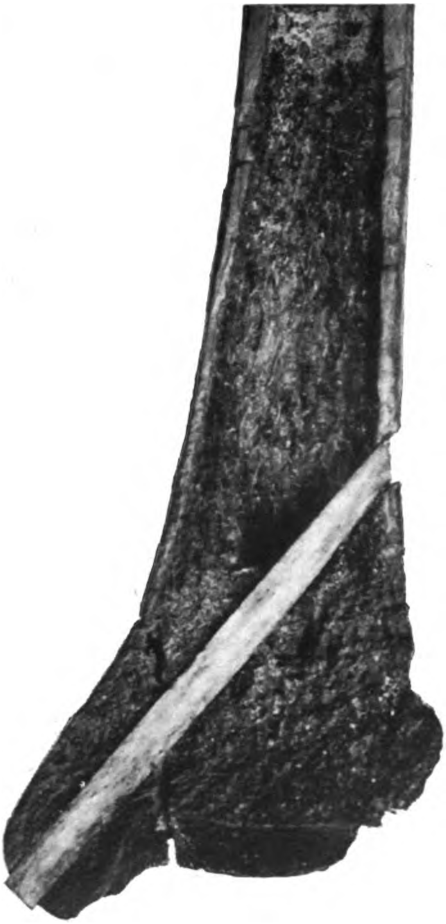


FIG. 113.—Section of prepared specimen of a peg transplant in the internal malleolus.

periosteum. It is cut tapering, slightly larger than the drill hole, so that when driven into position it will bind the fragment to the tibia. The transplant is driven sharply into the drill hole. The wound is closed and the extremity immobilized in plaster of Paris, to remain during convalescence.

FRACTURE-DISLOCATION OF THE SPINE.—Where there is a fracture of one or more vertebral bodies with angulation of the spinal canal or a fracture-dislocation of the spinal column, Palmer[13] recommends immediate exploratory laminectomy, followed by indirect permanent autoplastic ankylosis of the adjoining vertebræ above and below the defect. After completion of the laminectomy the incision is extended in each direction to expose two spinous processes above and two below the defect. The four spinous processes with their attached ligaments are split *en masse* with a thin, wide chisel, leaving two-thirds on one side and one-third on the other. The latter portion is broken over to make a gutter for the transplant.

A strong transplant, long enough to overlap the defect and the four split spinous processes, is taken from the spine of the tibia with a motor saw, with its periosteum remaining on it. The transplant is placed in the gutter in such a position that there will be bone-to-bone contact between it and the split spinous processes, with the periosteal side free. The transplant is secured in position by interrupted kangaroo-tendon sutures and the cleft closed over all. The soft parts are closed by absorbable sutures. The repair is immobilized for seven or eight weeks by a plaster-of-Paris jacket or on a fracture bed.

SUMMARY.

1. Autoplastic transplantation of bone is the operation of choice in those recent, simple fractures which require internal fixation.

2. Autoplastic fixation, when applied to recent fractures with the necessary attention to the essential details of the operation, produces very satisfactory anatomical and functional end-results. This is especially true in the neighborhood of joints, where the accurate apposition and support of the fragments prevent callus intrusion into the joints, permitting early complete restoration of joint activity.

3. The transplant is not resented by the tissues as a foreign body but is received in a kindly manner by them. It grafts to the fragments and supports the line of fracture. It becomes an integral part of its host, aiding the injured bone in the discharge of the functional demands put upon it. Later it is changed or absorbed as the functional need for its presence lessens or ceases.

4. The autoplastic repair of recent simple fractures is no more subject to infection than any other operation on bones with the same exposure. The transplant is a living bacteria-resisting structure. The tissues at the fracture have the normal resistance of the individual against infection. Suppuration indicates failure in the technic of the operation.

5. *Immobilization of the transplant to the fragments must be firmly established or grafting between them will fail.* The position of immobilization must be that of neutral muscular action. The muscles acting on the fragments must be relaxed by position to prevent displacement of the transplant. Intermittent muscular spasm acting on the repair will prevent grafting betweeen the transplant and the fragments and produce absorption of the less resistant structure.

6. The transplantation of bone for the internal fixation of recent simple fractures is capital surgery. It should not be undertaken without careful consideration, efficient assistance and the environments necessary to insure rigid asepsis.

CHAPTER VII.

AUTOPLASTIC REPAIR OF UNUNITED FRACTURES.

DESCRIPTION OF METHODS.

When a fracture fails to unite in a reasonable time, the immediate causation is a diminution or cessation of osteogenetic activity in the ends of the fragments. Unless activity of bone growth can be reëstablished, a permanent non-union will exist. Resection and approximation of the ends of the fragments do not alter the conditions, unless fresh, unchanged, healthy bone is reached. Even when this is accomplished, the original cause of failure of union may still exist as an active predominating factor, preventing bony union.

The requirements necessary to produce bony union are (*a*) removal of the sclerosed, eburnated bone; (*b*) fixation of the fragments in alignment; (*c*) stimulation of osteogenesis in the area of the ununited fracture.

The presence of metal or any foreign body as a material for fixation retards osteogenesis between the broken ends in a greater or less degree and hinders bony union of the ununited fracture.

The introduction of a transplant of fresh live bone into the non-union aligns the fragments and stimulates osteogenesis in the area of the ununited fracture where it had been inhibited. The transplant grows and stimulates the production of bony callus in and around the ununited fracture until full functional requirements are reached. After complete solidification of the fracture has occurred, the transplant and callus are absorbed as the functional requirements for their presence lessens or ceases. The new bone finally reaches a permanent basis, according to the requirements placed upon it.

There are four methods of application of autoplastic transplants in the treatment of ununited fractures.

1. MEDULLARY TRANSPLANT.—This method consists in the autoplastic grafting of a segment of fresh bone into the medullary canal of the injured bone across the non-union into each fragment.[14]

The medullary transplant is applicable and gives excellent results in the following conditions: In ununited fractures of the shaft of long single bones, as the humerus and femur. In parallel bones where both bones are ununited, as the radius and ulna, and the tibia and fibula. Where the ends of the fragments are not too badly destroyed by comminution, sclerosis or absorption. Where the medullary canal can be cleared of the deposit of hard, brittle callus without breaking or destroying the circle of original compact bone of the shaft.

The reëstablishment of the medullary canal in the fragments into healthy marrow and bone-to-bone apposition of the transplant to the wall of the medullary canal of each fragment, as well as stable immobilization during the necessary time for union, are the essentials to the grafting process.

The application of the medullary transplant is as follows:

After aseptic preparation of the field of operation, an incision is made exposing the non-union. The ends of the fragments are cleared from interposing fibrous tissue and freshened with as little destruction of bone as possible. A reamer slightly smaller than the original medullary canal is selected and the hard, brittle, eburnated callus is reamed out of the medullary canal of each fragment to a definite size. A transplant is cut from the crest of the tibia by caliper measurements to fit. It must not be too large, as the recipient fragments are very brittle and easily broken and the ferule action necessary to this operation lost if an oversized transplant is driven into either fragment. The transplant should be long enough to reach well into the healthy bone of each fragment, bridging the entire sclerosed area with fresh live bone. The transplant is usually obtained from the spine of the tibia, because that location furnishes a body of hard, compact bone of a shape and size necessary to get proper contact and of a kind of bone that acts vigorously as a stimulant to osteogenesis at the point of non-union in the recipient fragments. The periosteum should be removed from it, as it is to be buried in bone, and periosteum would act as any other fibrous interposing tissue, preventing bony union between the transplant and its host. The fitted transplant is introduced into the medullary cavity of each fragment across the defect, and the fragments are placed in anatomical alignment. The wound is closed in layers with catgut sutures obliterating all dead spaces and dressed with plain sterile gauze. The extremity is immobilized in alignment with plaster of Paris, the immobilization to remain until solid, bony union has occurred.

The transplant grafts to the fragments and stimulates the growth of new bone which eventually produces the deposition of solid, osseous tissue across the line of non-union.

2. PEG TRANSPLANT.—This method consists in the introduction of a transplant through the cancellous bone across the line of non-union which is situated near the end of a long bone in which there is no medul-

lary canal. The peg transplant may also be used in non-union of the patella. The transplant is anchored into compact bone wherever possible to give it more stability and better support.

The locations where non-union is most likely to follow fractures through cancellous bone are at the neck of the femur, the greater trochanter, the olecranon process and the patella. The non-union is exposed by a free longitudinal incision, and if possible, the interposing fibrous tissue is dissected from between the fragments. The ends of the fragments are freshened, either by a curette, rongeur forceps or an electric burr. With a gouge or reamer a suitable tunnel is made across the non-union through the cancellous bone. The tunnel should go through, into or against compact bone at either end.

A properly fitted peg transplant without its periosteum is driven snugly into the tunnel, bridging the non-union and fixing the fragments together. Periosteum is sutured over the ends of the transplant when exposed. The wound is closed and dressed in the usual manner. The repair is substantially immobilized in a plaster-of-Paris cast, which is to remain until solidification occurs.

The peg transplant grafts to the fragments, holds them in apposition and stimulates the growth of new bone between them, ultimately producing bony union.

3. Cortical Transplant.—This method consists in grafting a segment of fresh cortical bone into a gutter across the non-union.

In ununited fractures of one of two parallel long bones in which the supporting bone has united or is intact, as the radius, ulna or especially the tibia, where there is space to make the gutter, the cortical transplant is applicable and gives good results.

The essentials to the grafting process in this method of repair are: (*a*) a transplant of fresh cortical bone that has not been affected by the degenerative bone changes at the non-union; (*b*) a gutter in the cortex in line across the defect of a correct size to receive the graft; (*c*) apposition of the transplant to the gutter in the fragments so that each anatomical structure is in apposition to the same structure of the recipient fragments, *i. e.*, periosteum to periosteum, cortex to cortex and endosteum to endosteum; (*d*) stable immobilization during repair; (*e*) an aseptic wound.

After the usual preparation, the non-union is exposed by free incision, the ends of the fragments are cleared from fibrous tissue and freshened. The periosteum is incised in a longitudinal direction and turned back from the space to be used for a gutter. The fragments are held in proper alignment with clamps if necessary, while a gutter is cut longitudinally across the defect into both fragments with parallel motor saws. The saws are adjusted to cut the proper width for a gutter, from 8 mm. to 15 mm., according to the size and condition of the fragments. The length and location of the gutter depends upon whether the segment removed is to be transposed, replaced and used as the cortical transplant as proposed by Buchanan,[15] or whether the transplant is to be obtained from another bone or from the same bone at a distance from the non-union. It should be long enough in either case to extend into each fragment 6 cm. or 7 cm., or well into healthy non-sclerosed bone.

If the eburnation and sclerosis of the bone is limited to the non-union, the gutter may be cut twice as far or more into one fragment as in the other to secure a healthy segment of bone for a transplant. The segments are then reversed and replaced so that the long segment of healthy bone will bridge the non-union and the defect in the segments will be transferred to surroundings of healthy bone. The periosteum is sutured over all (Fig. 114).

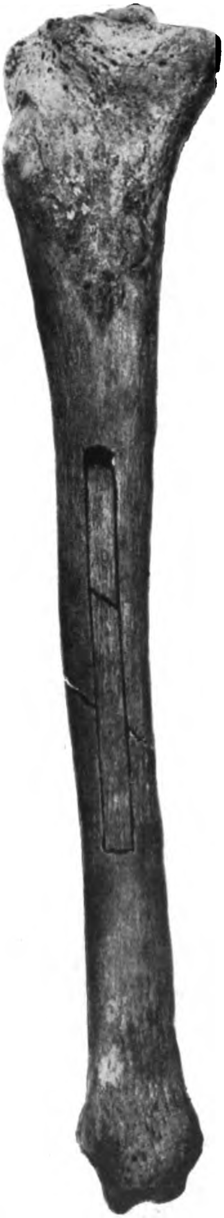


FIG. 114.—Buchanan's cortical transplant for ununited fracture of the tibia.

The advantages of this replacement of bone are that the operation requires only one wound to be made, and that wound on the same injured extremity. Another extremity is not invalided, confining the patient to bed during the entire convalescence.

If the bone in the immediate neighborhood of the non-union is destroyed, absorbed or sclerosed to such an extent that the bone removed from the gutter is not of a quality or quantity to be replaced, fresh osteogenetic bone must be obtained from some other location. When this is necessary, the transplant may be fastened across the non-union by the author's method of bevelled dovetail joints (Fig. 115).

A gutter is cut across the non-union equidistant into each fragment about 6 cm. or 7 cm., or well into healthy non-sclerosed bone. The outlines are marked with parallel motor saws, the sides are sawed with a single blade, cutting on a bevel toward and into the medullary canal. The ends are sawed with a blade not greater in diameter than the width of the gutter, on a bevel toward the medulary cavity, but away from the non-union. The bone dislodged from the gutter is preserved to fill in the

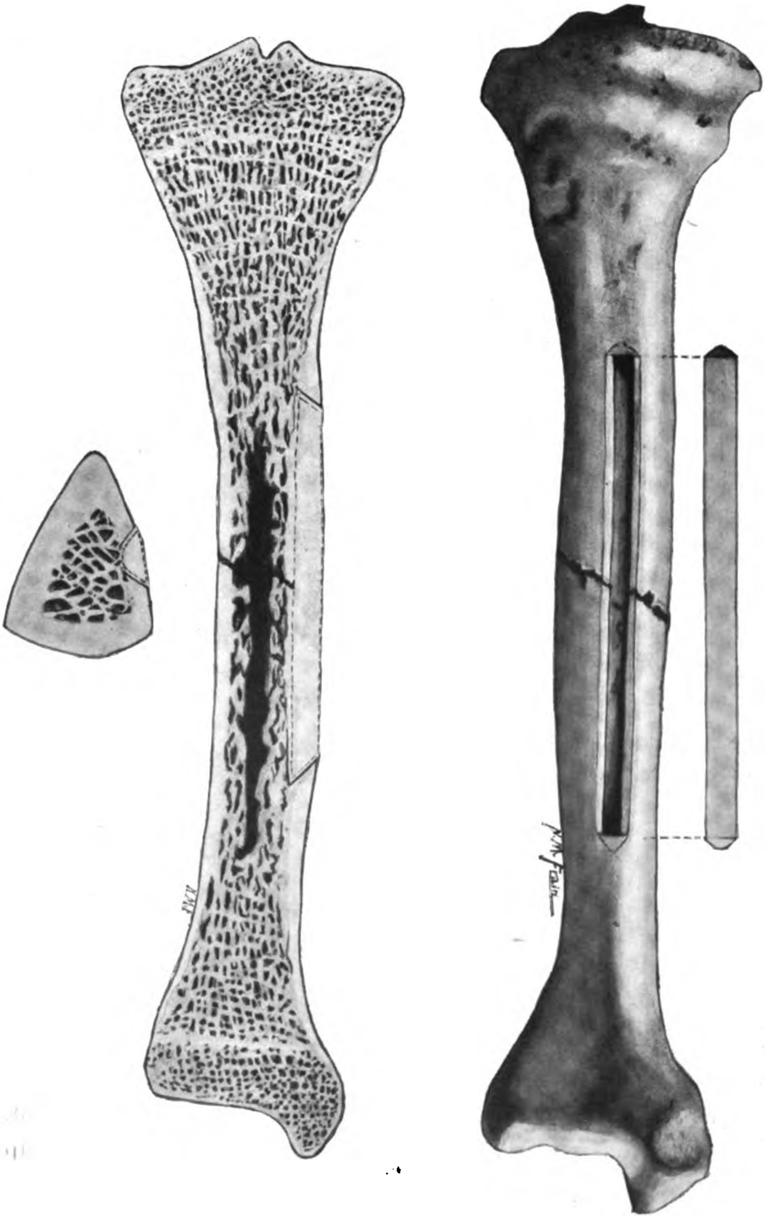


FIG. 115.—Cortical transplant for ununited fracture, showing bevelled dovetail joints.

space left by the removal of the graft. A transplant of fresh, healthy bone is usually secured from the internal surface of the tibia. A place is selected and the bone is exposed where a transplant can be obtained of the same shape and size as the combined discarded segments taken from the gutter. It is outlined and removed by the same method used in cutting the gutter, so that the different bevels of the transplant will fit the reverse bevels of the gutter. It is made slightly longer than the gutter, so that when in final position the bevelled ends will be forced underneath the undercut bevels of the ends of the gutter, making a substantial, close-fitting, bevelled dovetail joint at either end. Traction is made on the extremity to spread the non-union. The transplant is placed in position in the gutter. The traction is relaxed, allowing the muscles to contract, forcing the joints between the transplant and recipient bone into close contact, fixing the transplant firmly in the gutter across the non-union. If more support is needed, the transplant may be secured to the fragments by strands of kangaroo tendon passed through holes drilled in the fragments near the non-union.

The periosteum previously reflected from the bone on either side of the non-union is sutured with catgut over the transplant which is still covered with its own periosteum. The transplant retains sufficient vascular supply both from periosteal and endosteal sources. The wounds are closed in layers with absorbable sutures and enveloped in sterile gauze. The repair is carefully immobilized with a plaster-of-Paris cast to remain until solid bony union has occurred.

4. CONTACT TRANSPLANT.—This method consists in the grafting of a segment of fresh bone across the non-union to the cortical surface of each fragment beneath the periosteum. It is applicable in ununited

fractures where the fragments are very small or so hard and brittle that it is impossible to make a gutter for the graft and where there has been extensive destruction of the fragments by the original injury. It is especially applicable in those cases where extensive rarification and absorption of the fragments have occurred, the ends of which are far apart, pointed and undergoing retrogressive changes (Fig. 12). The contact transplant introduces the necessary osteogenetic stimulus to establish new proliferative bone activity and growth which eventually produces solid osseous union.

The operation for contact grafting is simple. The non-union is exposed by a free incision, the periosteum cut longitudinally and reflected from the area to which the transplant is to be applied. A flat transplant is taken from the tibia, usually the flat, internal surface. It is made long enough to bridge the non-union and to rest well on the healthy non-sclerosed bone of each fragment. The periosteum of the transplant is preserved with it. The endosteum is cut away so that the graft will have a fresh surface of compact bone for contact with the compact bone on either side of the non-union. The endosteum is not disturbed on that part of the graft which bridges the non-union.

The transplant is placed in position by simple contact with the bone on either side of the defect and the periosteum is sutured over all, holding the graft in bone contact and in position.

The wound is closed by layer sutures and dressed with sterile gauze. The non-union is immobilized with a plaster-of-Paris cast until solidification occurs.

The transplant grafts to the fragments on either side of the non-union and grows in thickness and strength accordimg to the functional demands upon it.

At times when the fragments of an ununited fracture are badly destroyed by absorption or sclerosis, it is advantageous to use one variety of grafting in one fragment and another in the other fragment, placing the graft in the medullary canal in one fragment and in a gutter in the other, or simply in contact with one fragment, as the conditions present may demand.

SPECIAL UNUNITED FRACTURES.

UNUNITED FRACTURES OF THE CLAVICLE.

The clavicle is fractured more often than any other bone in the human body, yet failure of union is extremely rare. When it occurs there is usually overlapping displacement because of the traction on the shoulder by the large muscles extending from the trunk. When ununited fractures of the clavicle produce deformity or functional disability sufficiently great to demand operative interference, the cortical transplant is applicable to stimulate osteogenetic activity and remedy the defect in the bone.

As a preliminary to the operation the shoulder is fixed in a position upward, outward and backward, by a Sayre dressing. The upper extremity is immobilized against the trunk by plaster of Paris. This expedient fixes the outer fragment of the clavicle during the operation and subsequent treatment without covering the field of operation.

An incision following the clavicle exposes the defect in the bone. The fibrous and other interposing tissue are removed. The ends are freshened and fitted to each other in anatomical alignment. The periosteum is stripped back and a gutter is cut across the defect equidistant in the fragments. A gutter is cut, about 6 cm. long and 1 cm. wide, through the cortex into the fragments for the reception of the transplant. The large vessels and nerves passing behind the clavicle are continually in danger of injury and should be carefully protected. A transplant of the same length and width and sufficiently thick to fill the gutter is cut from the crest of the tibia. The periosteum is retained intact on it during the transfer. The transplant is wedged into the gutter with the cut surfaces in apposition to the cut surfaces of the gutter, and with the periosteal surface exposed. The periosteum which was reflected from the clavicle is replaced and sutured over the transplant. A strand of kangaroo tendon is secured around each end of the transplant and the clavicle to increase the stability of the repair. The wound is closed by sutures and dressed with aseptic gauze.

The immobilizing dressing previously applied is not removed until the transplant has grafted into the fragments of the clavicle and closed the defect.

The history of the following personal case illustrates the method described for the treatment of ununited fracture of the clavicle:

CASE No. 18.—Ununited fracture of the clavicle.—J. Z.; Pole; laborer; aged twenty-nine years; was injured in a railroad wreck March 30, 1914. He was an inmate of a hospital for the following six months, recovering from his various injuries. He was admitted to Cook County Hospital December 10, 1914, with non-union of the left clavicle. Examination showed a robust young man with crepitus and a false point of motion at the junction of the outer and middle thirds of the left clavicle. A röntgenogram revealed an old ununited fracture of the clavicle.

Operation for the repair of the non-union by cortical transplant was performed two days later. The non-union was exposed by a direct incision along the clavicle and the interposing fibrous material was excised. The fragments were held in alignment by a Lowman's clamp while a gutter 1 cm. wide was cut with parallel motor saws across the line of fracture 3 cm. into each fragment. A transplant of the same width and length was sawed from the spine of the tibia. The periosteum was retained upon it. It was mortised into the gutter across the ununited fracture in the clavicle, with its periosteal surface exposed and its cut surfaces buried in the gutter. The periosteum of the clavicle which had previously been reflected was sutured over it. The stability of the repair was reinforced by strands of kangaroo tendon tied around the clavicle and the transplant.

The wound was closed by catgut sutures. The upper extremity was immobilized by a plaster-of-Paris cast with the shoulder thrown upward, outward and backward, to retain the alignment of the fragments of the clavicle.

The non-union was solidly united at the end of eight weeks.

The medullary transplant is applicable to ununited fractures of the clavicle where the changes in the ends of the fragments are slight. It may be successfully used where the medullary canal can be reëstablished.

UNUNITED FRACTURES OF THE HUMERUS.

UNUNITED FRACTURES OF THE SHAFT OF THE HUMERUS.—This non-union should be repaired with the medullary transplant.

The pseudarthrosis is exposed by an incision along the outer border of the biceps muscle. The ends of the fragments are developed, freshened, and fitted. The medullary canal in each fragment is cleared, up to healthy marrow, of all eburnated, sclerotic callus by means of a hand reamer of the proper size. A transplant is cut from the spine of the tibia, by accurate caliper measurements, to fit the space prepared for it in the fragments of the humerus. The periosteum is removed from the transplant. The graft is placed in the medullary canal of each fragment across the non-union. The wound is closed by layer sutures and the arm immobilized by a plaster-of-Paris cast in such a position that there will be no angular leverage at the non-union which might cause pressure necrosis and absorption without union between the transplant and the recipient fragments. The immobilization is retained until solidification occurs.

The following case is cited, through the courtesy of Dr. Lawrence Ryan, to illustrate the application of medullary transplants to ununited fractures of the shaft of the humerus:

CASE No. 19.—Ununited fracture of the shaft of the humerus.—H. M.; German-American; pressman; aged twenty-five years; sustained a compound comminuted fracture of the left arm in an elevator accident November 17, 1913. There was considerable destruction of soft tissues. Severe infection followed the injury. Without waiting for complete healing of the wound, an operation was performed for ununited fracture February 4, 1914.

The ends of the fragments were freshened and fitted with a saw. They were secured in apposition with bronze wire. A severe infection developed ten days after operation, necessitating the removal of the wire. The wound was healed in six months. Non-union of the fracture again resulted. The right arm had previously been amputated and the patient was dependent upon the left arm.

He was admitted to the service of Dr. Ryan at Cook County Hospital January 15, 1915. Examination showed a healthy young man with a false point of motion in the left arm (Fig. 116). A röntgenogram revealed a non-union of the lower third of the humerus without apposition of the fragments (Fig. 117).

One week later operation was performed for autoplastic repair of the non-union. The fragments were developed and freed from fibrous tissue. The ends were freshened. The old callus was removed from the medullary canals of the fragments. A medullary transplant was taken from the crest of the tibia about 12 cm. in length and 1.8 cm. in width. The transplant was inserted into the medullary canals of the fragments. The wounds were closed. The upper extremity was immobilized with plaster of Paris.

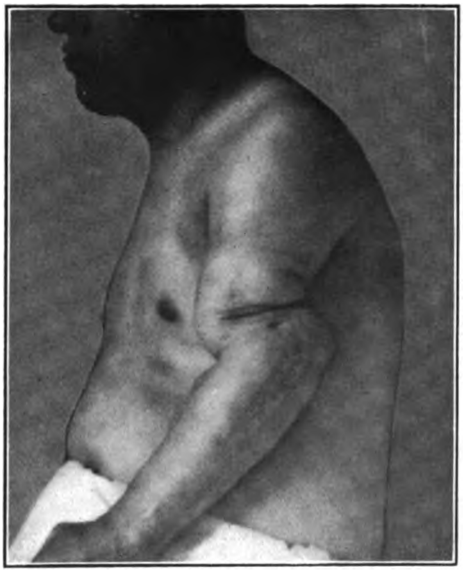


FIG. 116.—Case No. 19. Photograph of ununited fracture of the arm.

The cast was removed in six weeks when bony union was present.

A röntgenogram, taken six months after operation, shows the transplant grafted to each fragment,

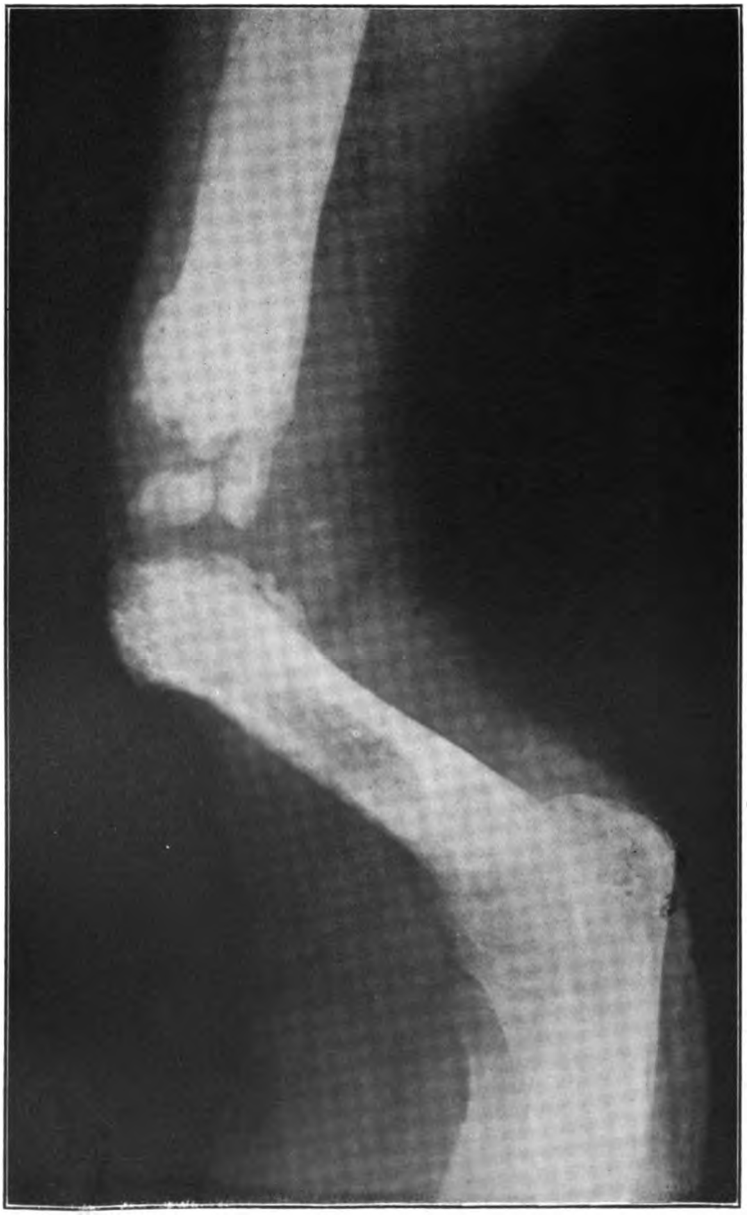


FIG. 117.—Case No. 19. Röntgenogram of ununited fracture of the humerus.

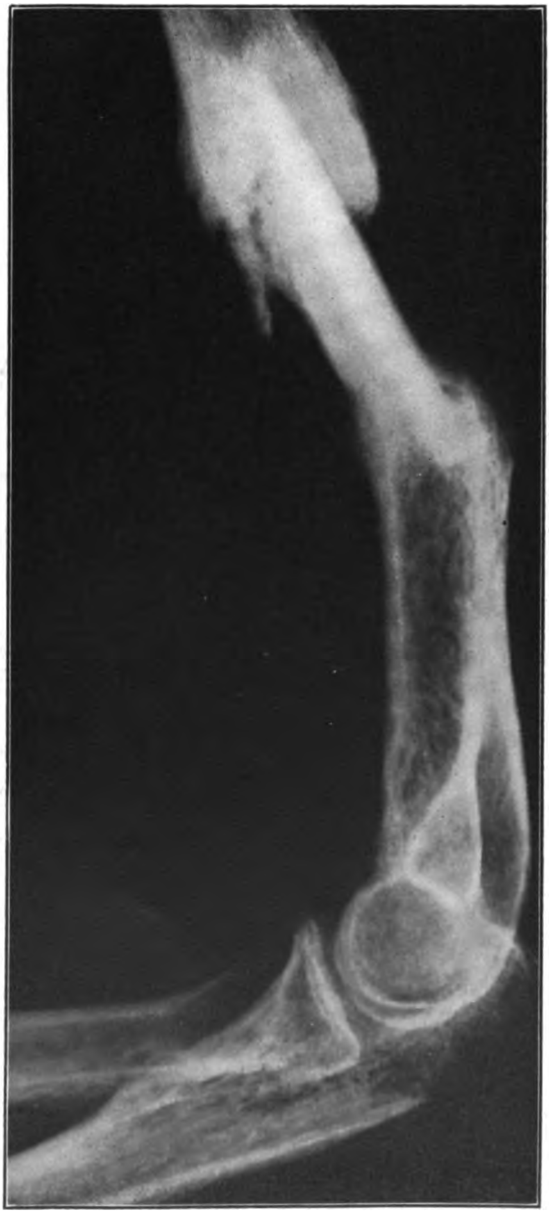


FIG. 118.—Case No. 19. Röntgenogram of repair of ununited fracture of the humerus by a medullary transplant, six months after operation.

bridging the defect (Fig. 118). The patient recovered with a useful arm (Fig. 119).

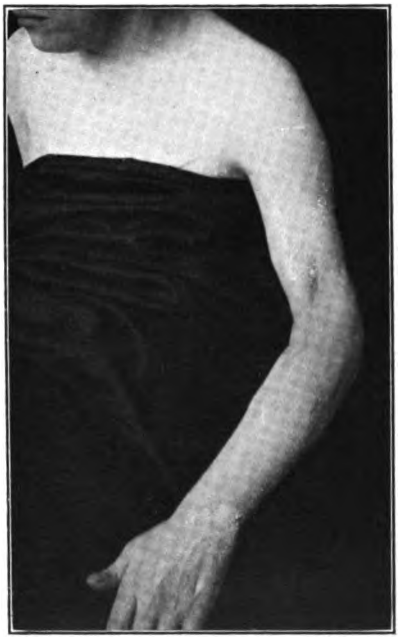


FIG. 119.—Case No. 19. Photograph of arm, six months after operation.

UNUNITED FRACTURES OF THE FOREARM.

1. UNUNITED FRACTURES OF THE OLECRANON.—When recent simple fractures of the olecranon are reduced by manipulation and position and immobilized by external splints, fibrous union is the expected result. With close fibrous union the functional result is good, but if the band of union is weak or becomes stretched and attenuated, functional ability of the arm is more or less impaired. If the debility is of sufficient consequence to necessitate interference, bony union may be produced by fixing the small fragment in place with a peg transplant from the tibia.

The manner of application of the transplant is shown in the longitudinal section of the olecranon prepared to illustrate the application of the transplant to recent fractures (Fig. 71).

The olecranon is exposed by an incision over the point of the elbow. If the fibrous tissue between the end of the shaft and the fragment is extensive, it is removed. The fragment is held in its proper anatomical position while a drill is forced through the fragment into the shaft of the ulna in the same direction as in recent fracture. A transplant of hard bone from the spine of the tibia, without periosteum, is driven into the canal until it penetrates or is in contact with the compact bone of the anterior part of the ulna. The olecranon end of the graft is covered, if possible, by periosteum. The wound is closed in layers by absorbable sutures. The arm is dressed in extension and immobilized by a plaster-of-Paris cast.

The following personal case shows the results in an ununited fracture of the olecranon:

CASE No. 20.—Ununited fracture of the olecranon.—W. L.; German-American; painter; aged fifty years; injured his left elbow by a fall in August, 1914. He was treated by external splints for four weeks without obtaining union.

Eight weeks after injury open operation was performed and the fragment wired in position. Ten weeks later he was admitted to Cook County Hospital with non-union.

Examination showed a healthy man, a movable olecranon process, without functional extension of the forearm. He had ulnar paralysis. A röntgenogram showed an ununited fracture of the olecranon process and a broken wire suture (Fig. 120).

Operation for repair of the non-union by transplantation of bone was performed sixteen weeks after the original injury. The broken wire was removed. A small, tapering transplant was taken from the spine of the tibia 5 cm. long, 5 mm. wide and thick, without periosteum. A canal was made through the fragment across the defect into the ulna and the graft driven into it. The ulnar nerve was dissected from the scar and surrounded with fascia.

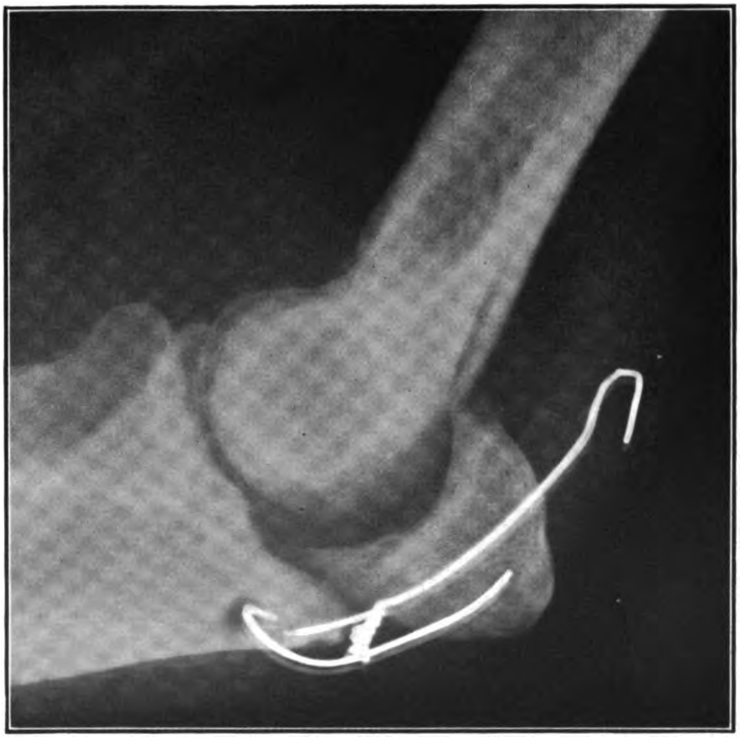


FIG. 120.—Case No. 20. Röntgenogram of ununited fracture of the olecranon which has been wired for non-union.

A röntgenogram, taken eight weeks after the operation, shows union with callus in the defect and upon the posterior surface of the olecranon and ulna (Fig. 121).

Recovery resulted with bony union of the olecranon and functional extension of the forearm. There was recovery from the ulnar paralysis.

2. UNUNITED FRACTURES OF THE RADIUS OR ULNA.—When this condition occurs in the shaft of either

bone, it usually is a sequence of fracture of both bones of the forearm in which union of one bone only has followed the injury. Under these conditions grafting

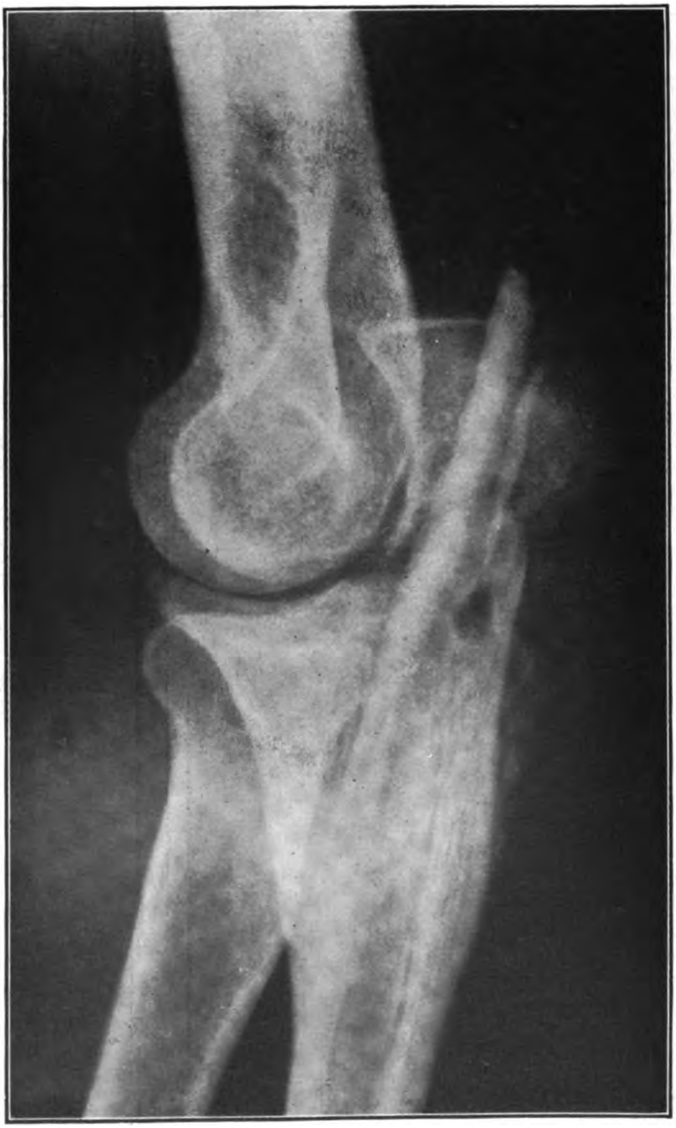


FIG. 121.—Case No. 20. Röntgenogram of repair of ununited fracture of the olecranon by a peg transplant.

of fresh bone across the defect is indicated. The medullary transplant is not applicable because the recipient fragments must be placed at an angle to each other to allow its introduction into the medullary canal, a maneuver not possible with an intact parallel bone. Either the cortical or contact graft should be used, depending upon the amount of disintegration and atrophy of the fragments.

To place the transplant, an incision is made over the non-union. The periosteum is stripped back from the defect, exposing the ununited bone. If the condition of the fragments will allow the cutting of a gutter, it should be done and a transplant inserted. If there is angular displacement of the fragments, the gutter should be cut across the angle, so that the transplant will hold the fragments in alignment after reduction. Before cutting the gutter, the fragments are placed in correct rotation, with the forearm midway between pronation and supination. The gutter is cut with parallel saws, adapted to the small size of the bone. The gutter is extended through the callus that fills the medullary canal, so that the freshly cut bone of the transplant can be placed in contact with the freshly cut solid bone of the opposite wall of the medullary canal. The transplant is cut with the same adjustment of saws from the crest of the tibia, or from the posterior border of the ulna if the defect is in the radius. The periosteum is retained on it. The endosteum, if present, is trimmed away to give bone-to-bone contact at the bottom of the gutter. The transplant is wedged into the gutter in the recipient fragments and fastened in place by kangaroo-tendon sutures. The periosteum previously stripped back is sutured over the graft. The wound is closed in layers by catgut sutures and dressed with sterile gauze. The forearm is placed across the front of the chest midway between pronation and supination and firmly immobilized by a Velpeau dressing of plaster of Paris (Fig. 55). The immobilization is not disturbed during convalescence.

If the fragments at the point of non-union are so destroyed or atrophied that there is not sufficient bone in which to make the gutter, a contact transplant should be used. The fibrous tissue and periosteum are reflected from the side of each fragment and a flat transplant retaining its periosteum is placed across the non-union so that it has a freshly cut compact bone contact with each fragment. It is secured to the fragments by strands of kangaroo tendon. The reflected periosteum is sutured over all.

The following history of a personal case illustrates the successful application of the cortical graft to the shaft of the radius after fixation of the non-union by a Lane plate had resulted in a failure:

CASE No. 21.—Ununited fracture of the radius.—S. S.; Italian; laborer; aged thirty-eight years. Patient sustained a compound fracture of both bones of the right forearm by falling from a moving railroad train on January 2, 1914. He was taken to a near-by hospital where the injury was treated. Immobilization of the arm was continued for four months without bony union of the radius. Union of the fracture in the ulna resulted.

One month later, in another hospital, he had an open operation for non-union of the radius. The ends of the bone were approximated with a vanadium steel plate, but bony union did not follow.

The patient entered Cook County Hospital October 14, 1914. He was not able to work because of a false point of motion in the radius, pain in the wrist and inability to rotate the forearm.

Examination showed deformity, false point of motion and crepitus at the middle third of the right radius. A röntgenogram revealed an intact ulna and a non-union of the radius with a metal plate across the defect in the bone (Fig. 122).

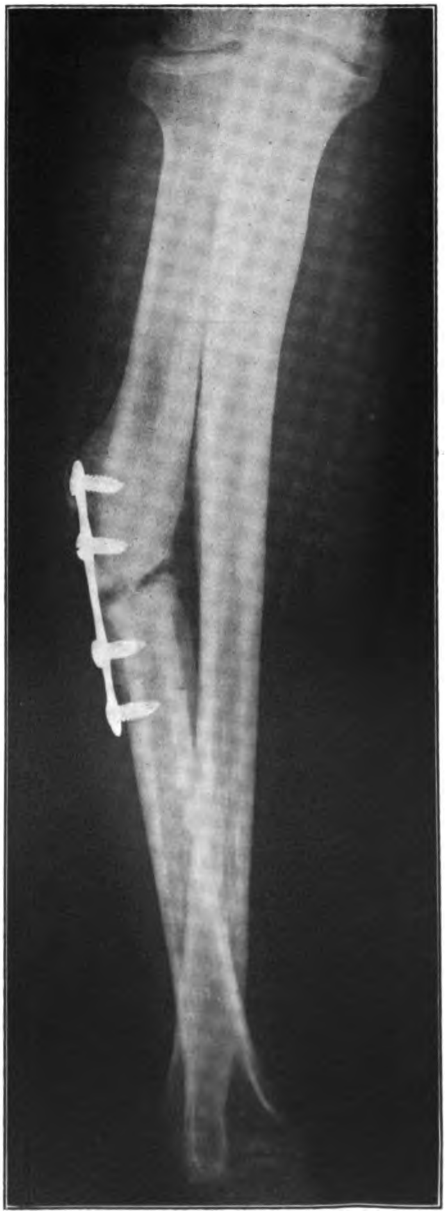


FIG. 122.—Case No. 21. Röntgenogram of ununited fracture of the radius, in which repair of the non-union had been attempted by a Lane plate.

Operation was performed ten days later to remove the metal plate and to repair the non-union of the

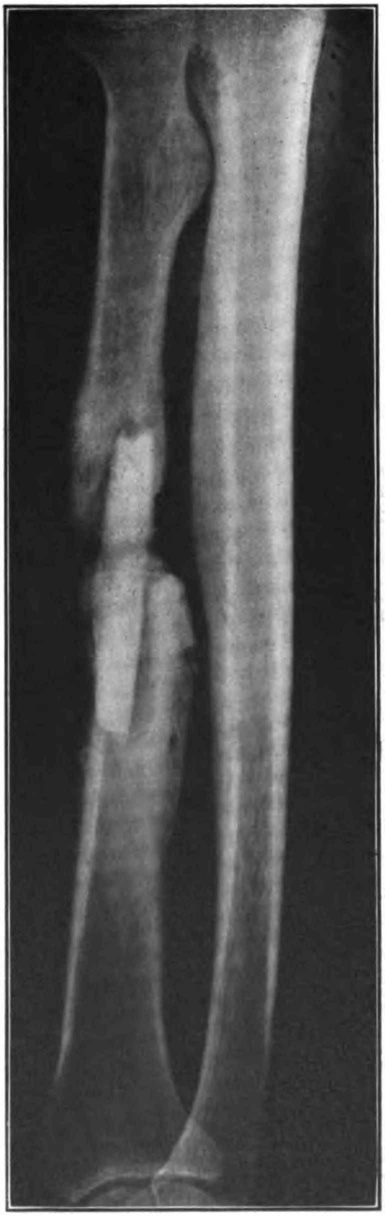


Fig. 123.—Case No. 21. Röntgenogram of ununited fracture of the radius repaired by a cortical transplant, seven weeks after operation.

radius. The plate was partly buried by exuberant bone loosely fastened to the radius. It was found to be holding the fragments in faulty relationship of rotation. When the plate was removed it was found that the four large screws had passed almost through the whole diameter of the radius, causing extensive disintegration and eburnation of the bone. The periosteum was stripped back. The ends of the fragments were freshened and apposed in the correct relationship of rotation, midway between pronation and supination. The fragments were held by a clamp while a gutter was cut with parallel motor saws and chisel across the defect, 1 cm. wide and 3 cm. in length, in each fragment and in depth to the opposite compact bony wall. A transplant corresponding in shape and size taken from the tibia with its periosteum intact was wedged tightly into the gutter and secured by two strands of kangaroo tendon. The periosteum was sutured over it. The wound was closed by layer sutures and the extremity immobilized by a Velpeau plaster dressing.

The arm was not disturbed for seven weeks, when solid union was found to have taken place (Fig. 123).

UNUNITED FRACTURES OF THE FEMUR.

1. UNUNITED FRACTURES OF THE NECK OF THE FEMUR.—Non-union, perhaps, more frequently follows fracture of the neck of the femur than any other fracture, and none can produce more functional disability. Intracapsular fracture usually heals with pseudarthrosis (Fig. 124).

The prospects of recovery by the use of the autoplastic interosseous transplant, to fix the non-union and to stimulate new growth of bone in the defect between the fragments, are sufficiently good to indicate the operation, if the age and physical condition of the patient do not prohibit the necessary operative procedure and the prolonged immobilization necessary to obtain successful results.

The details of the operation are the same as for recent fracture of the neck (Fig. 77).

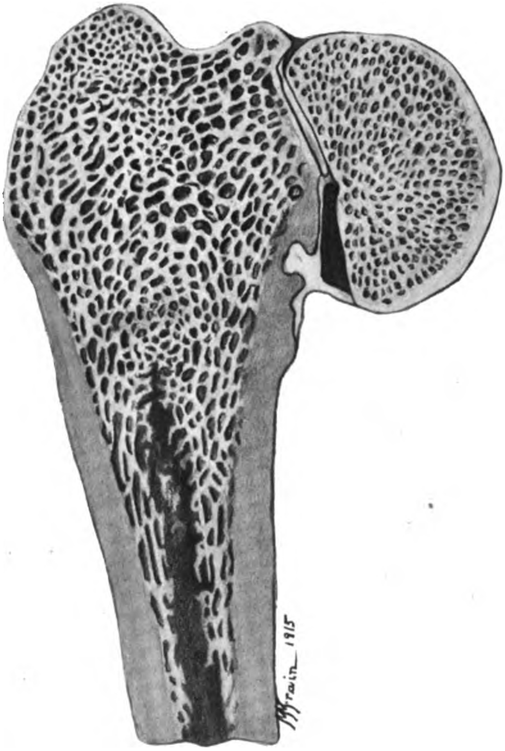


FIG. 124.—Pseudarthrosis of the neck of the femur.

The operation is performed on a Hawley fracture table. An incision is made in a line perpendicular to the anterior superior spine of the ilium over the pseudarthrosis, exposing the defect in the bone. The surfaces of the old fracture are freshened, when possible, by a curette or rongeur forceps, destroying as little bone substance as possible. Another incision is made on the outside of the thigh, exposing the shaft of the femur below the greater trochanter, and a fibular transplant is placed across the non-union in the same manner as for a recent fracture in the same location. The transplant mechanically holds the fragments together and introduces a bond of healthy bone across the pseudarthrosis which acts both as a nucleus and as a stimulant for the growth of new bone in the defect. When there is sufficient vitality of the upper fragment and when the proper conditions of stable immobilization of the transplant and pseudarthrosis are maintained, the transplant grafts to the bony fragments on either side of the defect. This repairs the non-union, at first with the strength of the transplant, and later by the additional strength of the new bone deposited in and around the defect as a result of the osteogenic stimulus of the fresh graft.

For ideal grafting of a transplant across any non-union in any bone, it is necessary to extend it into the fragments distal from the non-union until a bed is secured in live, healthy, non-sclerosed bone.

In pseudarthrosis of the neck of the femur of long standing it is often impossible to secure a bed for the transplant in the upper fragment in healthy, non-sclerosed bone, because of the absorption and degenerative changes which have occurred in the entire upper fragment following the original injury, because of its limited vascular and nerve supply and its detachment from its proper bone contact with consequent loss of function. On account of these conditions pseudarthrosis of the neck of the femur becomes the most difficult and uncertain of the non-unions to remedy by autoplastic grafting.

It is probable that a live transplant grafted to the lower fragment and projecting into an upper fragment undergoing degenerative changes will itself enlarge and also cause a growth of new bone cells to project into and infiltrate the upper fragment, and if immobilization is maintained until the process is sufficiently advanced, eventually will produce a solidification of the defect.

The immobilization needed to secure good end-results is difficult to attain, burdensome to the patient, and must be prolonged in duration.

To obtain grafting of the transplant to the fragments, it is imperative that all motion between the fragments, and between the fragments and the transplant be prevented. Because of the spasmodic action and leverage of the powerful muscles attached to the upper end of the lower fragment, and because of the small size and location of the upper fragment, and also the weight and great leverage of the lower fragment, pseudarthrosis of the neck of the femur is the most difficult of the non-unions to immobilize for the length of time necessary to secure bony union between the fragments. Traction and spasm of the muscles are overcome by the position of extreme abduction and external rotation of the thigh. The fragments are immobilized in that position by a body plaster-of-Paris cast extending from the axilla to the toes and including the opposite thigh in abduction (Fig. 78).

The immobilization of the hip must be maintained until the process of grafting between the transplant and the recipient fragments, and the solidification between the fragments themselves have attained a stability that will prevent movement between the transplant and its host, otherwise the autoplastic operation will result in failure. A long time is required, especially if there is need of regeneration of the small fragment. The length of time required for repair and regeneration of bone depends, in the individual case, upon the length of time after the original fracture, the condition of the small fragment, as to its viability, the amount of degeneration and absorption and finally, upon the general condition of the patient.

Examination by röntgenograms will demonstrate the condition of the repair and should determine the length of time of immobilization. Body-weight bearing should not be allowed until a röntgenogram shows repair of the pseudarthrosis, and not until functional movements of the hip-joint have been restored.

Through the courtesy of Dr. C. M. Jacobs, the author operated upon the following case of ununited fracture of the neck of the femur:

CASE No. 22.—Ununited fracture of the neck of the femur.—F. M.; American; lather; aged thirty-six years; was admitted to Cook County Hospital January 5, 1915, suffering from an old injury to the left hip. The patient had fallen from a scaffold eighteen months previously and sustained a fracture of the neck of the femur.

Examination showed a robust, healthy-looking man with a useless left lower extremity. Bryant's line was 2.5 cm. shorter on the left side than on the opposite side. The extremity was atrophied. The circumference of the thigh was 5 cm. less than the normal leg. Movements at the hip-joint were very limited. A röntgenogram revealed an old ununited fracture of the neck of the left femur. The upper fragment was mottled and appeared to be undergoing degeneration (Fig. 125). A luetic history was given of fourteen years' duration.

Ten days later an open operation was performed to repair the non-union. It was exposed by an incision below the anterior spine of the ilium. The ends of the fragments were freshened with a sharp curette. A second incision was made down to the femur below the greater trochanter. With a gouge and hand reamer a canal to receive the peg transplant was cut across the line of the ununited fracture into the head of the femur. A direction was chosen so that the transplant when introduced would rest on the hard, compact bone of the shaft of the femur at its junction with the neck and at the same time enter the head of the bone.

A section of the fibula from the same leg, stripped of its periosteum, 11 cm. in length was used for the transplant. The opening in the compact wall of the shaft was fitted to the irregularities of the transplant. It was driven firmly into the canal across the non-union into the head of the femur. The wounds were closed in layers with absorbable sutures and dressed with a large quantity of sterile gauze. The hip was immobilized in extreme abduction and extreme external rotation by a strong, double-spica body cast, extending from the axilla to the toes on the injured side and to the knee on the opposite side (Fig. 78).

A röntgenogram, taken six months after operation, shows the transplant grafted across the non-union with callus formation at the defect and beginning regeneration of the capital fragment (Fig. 126). A röntgenogram of the defect in the fibula shows no regeneration of bone (Fig. 127).

Six months after operation the patient was walking with a cane with a fairly useful extremity. There was considerable limitation of motion in the hip-joint (Fig. 128).

2. UNUNITED FRACTURES OF THE SHAFT OF THE FEMUR.—The medullary transplant should be used in non-union of the shaft of the femur. It furnishes a strong alignment fixation as well as the necessary osteoblastic stimulus to remedy the non-union.

The non-union is exposed by an incision through the soft parts of the thigh anterolateral to the defect.

The fragments are developed and cleared from all interposing tissues. The ends are freshened and fitted

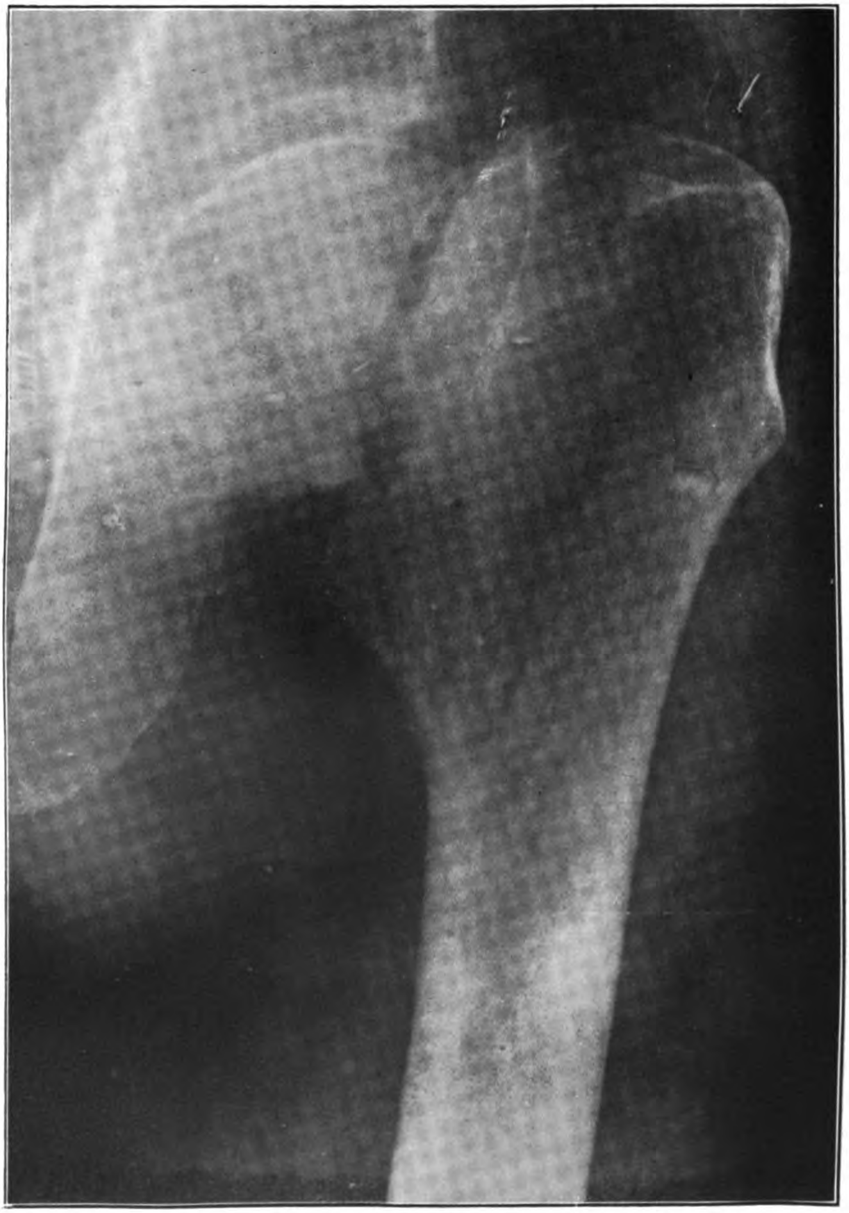


FIG. 125.—Case No. 22. Röntgenogram of ununited fracture of the neck of the femur, showing degeneration of the head.

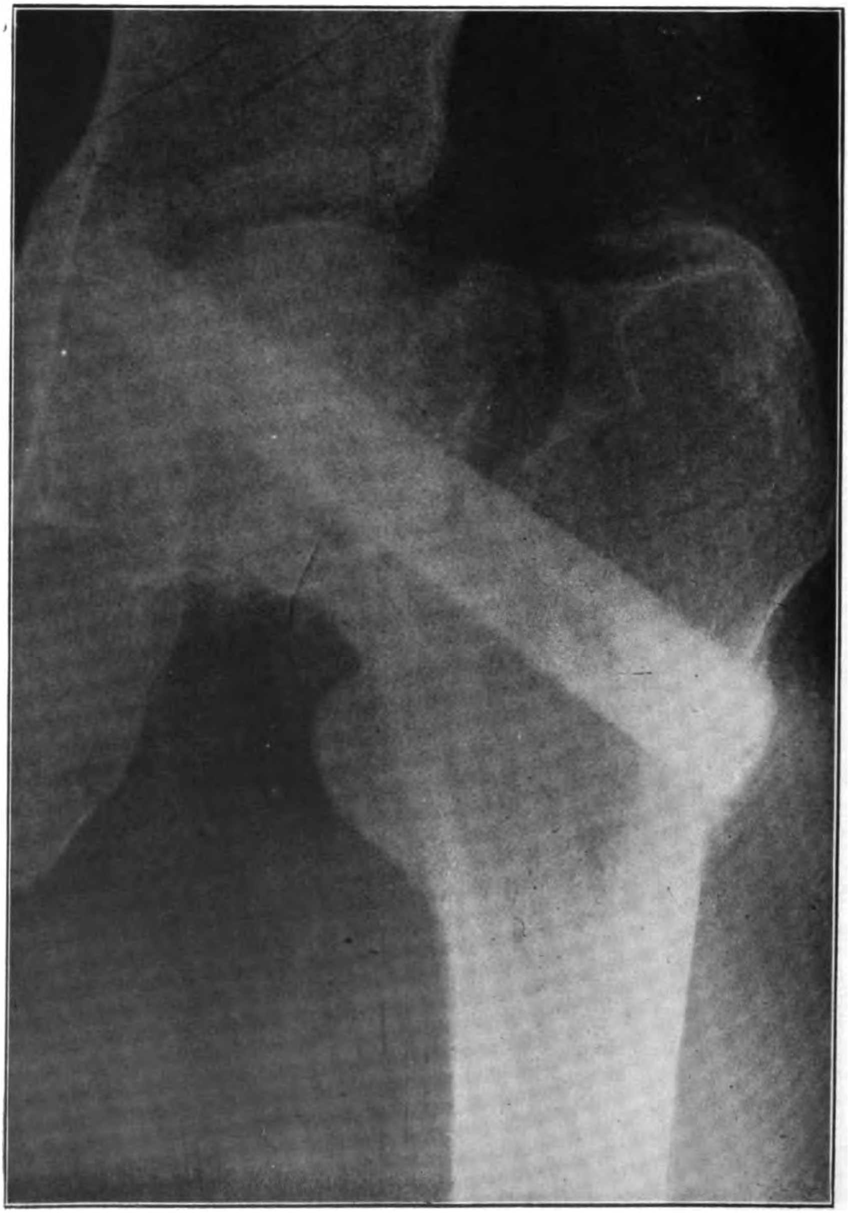


FIG. 126.—Case No. 22. Röntgenogram of repair of ununited fracture of the neck of the femur by a fibular peg transplant, six months after operation.

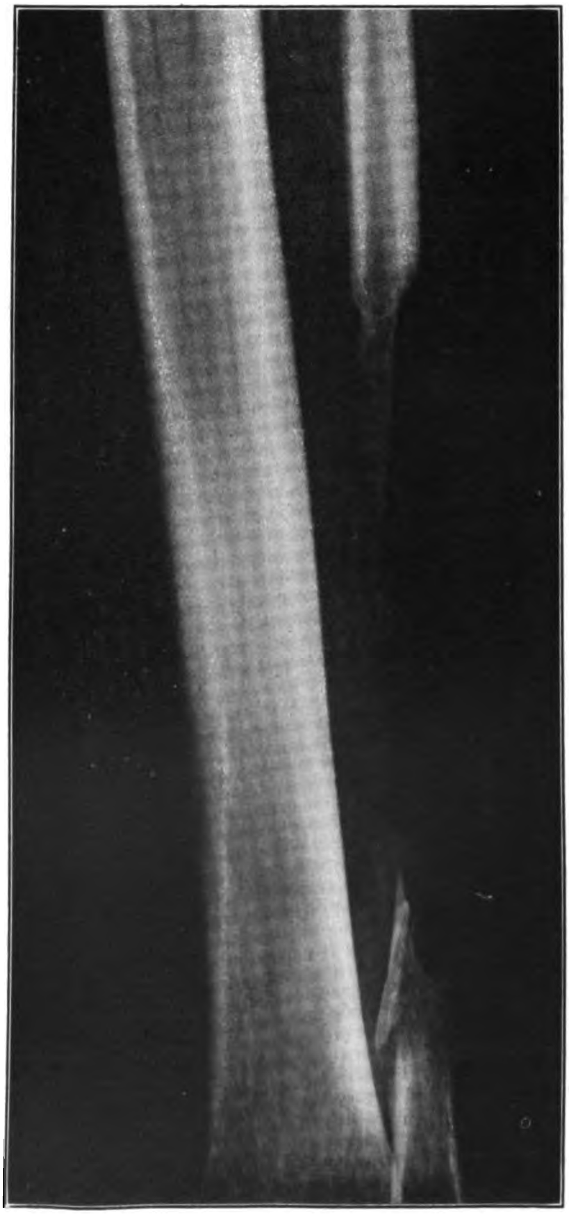


FIG. 127.—Case No. 22. Röntgenogram, showing defect in fibula, six months after operation.

by the saw or other bone-cutting instruments. A hand-propelled bone reamer, slightly smaller than the original medullary canal, is introduced into the medullary canal of each fragment and all sclerotic bone callus carefully removed. The use of the reamer is continued until non-sclerosed, healthy bone and live marrow are reached in each fragment.

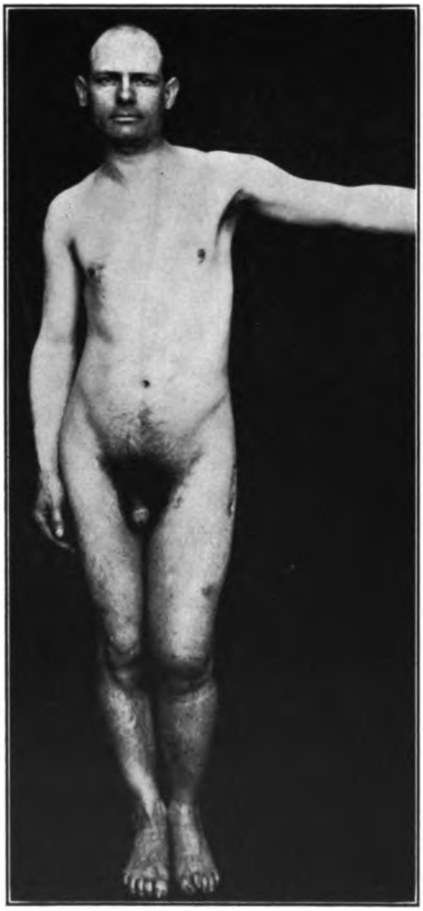


Fig. 128.—Photograph, six months after operation, standing erect with both feet together on the floor, in normal position of rotation of the injured (left) extremity.

With accurate caliper measurements a transplant without periosteum is cut from the spine of the tibia of the same extremity to fit the graft bed in the fragments. The fit between the transplant and its host must be accurate. An oversized transplant will shatter the brittle fragments if roughly introduced into them, and a transplant too small will make doubtful bone contact for grafting and give poor alignment support. The graft is gently introduced and the fragments aligned. The wounds are closed, dressed and the whole lower extremity immobilized by a body plaster-of-Paris cast. The repair should be supported by a cast applied sufficiently snug to prevent any angulation at the line of fracture, as angulation after alignment might cause pressure necrosis with absorption of the transplant or its host and failure of grafting. The plaster-of-Paris body cast should include the pelvis and whole lower extremity, and the immobilization should be continued until complete osseous union has occurred.

The following personal case illustrates the use of the medullary transplant in ununited fractures of the shaft of the femur:

CASE No. 23.—Ununited fracture of the shaft of the femur.—F. V.; Italo-American; fruit dealer; aged twenty-five years; was admitted to Cook County Hospital with an infected gunshot fracture of the left femur. Because of the infection and sloughing of the soft parts, it was necessary to remove the extension apparatus and treat the wounds of the soft parts.

Three months after the injury a röntgenogram revealed non-union with malposition of the fragments (Fig. 129).

Operation was performed to obtain alignment of the fragments and repair of the non-union. The fragments were developed and the old callus removed. The medullary canals of the fragments were opened

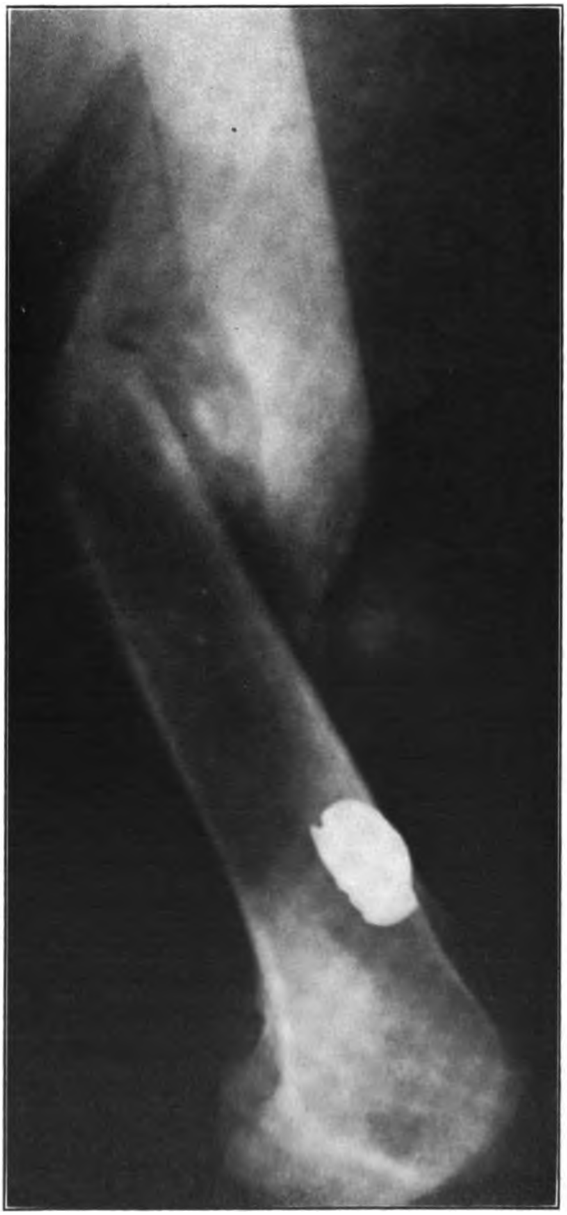


FIG. 129.—Case No. 23. Röntgenogram of ununited fracture of the shaft of the femur, also showing the bullet which caused the injury.

with a reamer. A medullary transplant was cut from the crest of the tibia, 10 cm. in length. The diameter of the transplant was cut, by caliper measurements, to fit the medullary canal. The periosteum was removed. The transplant was inserted into the fragments and the extremity aligned. The wounds were closed. The repair was immobilized in a plaster-of-Paris body cast extending to the toes on the injured side.

A röntgenogram, taken six weeks after operation, shows the transplant grafted into the medullary canal of each fragment with callus formation at the line of fracture (Fig. 130).

FRACTURE OF THE PATELLA WITH IMPAIRED UNION. —Refracture of the patella from insignificant violence occasionally occurs after apparent recovery with bony union following a previous fracture. Such an accident shows a defective, weakened condition of the bone. This difficulty may be overcome by stimulating new bone growth by grafting a transplant of fresh bone into the fragments of the patella across the line of fracture.

Non-union or fibrous union of the patella, resulting in greater or less separation of the fragments with a variable degree of disability of the extremity, is the method of recovery in recent fractures of the patella when treated expectantly without open operation and suture. If the functional disability is sufficiently great to demand operative interference, bony union may be stimulated and the line of fracture strengthened by grafting fresh bone across the deformity in the patella after the fragments have been approximated by absorbable, direct suture.

The operation for refracture of the patella and for disabling fibrous union and non-union following fracture of the patella are practically identical.

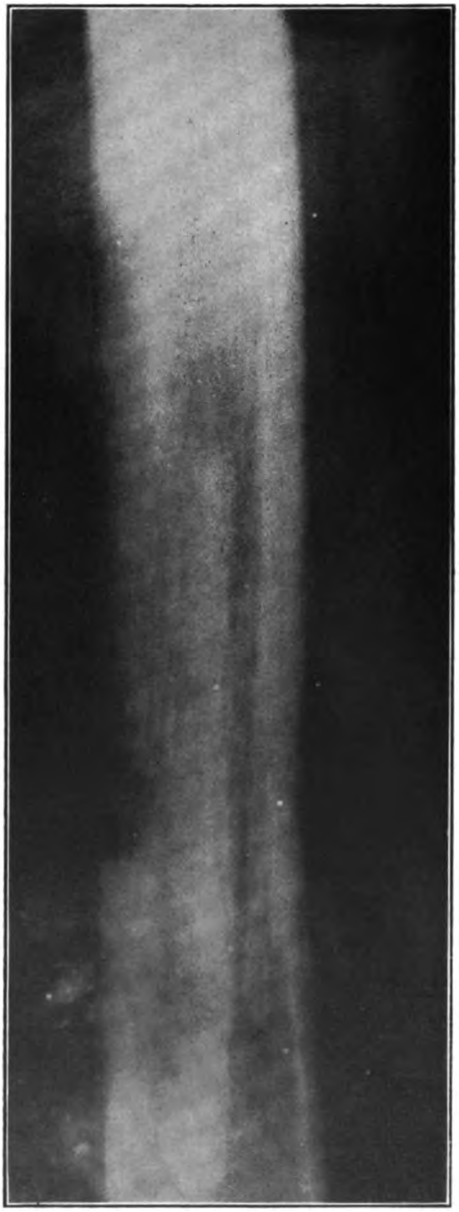


FIG. 130.—Case No. 23. Röntgenogram of repair of ununited fracture of the shaft of the femur by a medullary transplant from the crest of the tibia.

The fragments of the patella are exposed by the usual horseshoe incision for the open suture of recent fracture. In the refracture of the patella, the broken surfaces are cleared of interposing tissue and freshened. The transplant is applied in conjunction with the usual method of suture of the fragments. In fibrous union of fracture of the patella, all fibrous and other interposing tissue are removed by dissection. The eburnated and rounded surfaces of the old fracture are denuded and fitted to each other until the fresh surfaces of the fragments can be apposed without the intervention of sclerotic bone or other tissue, and the transplant is applied across the line of fracture during the operation for suture of the fragments.

Two methods of application of the transplant have been suggested.

1. The fragments may be grafted by a flat, contact transplant. A flat, quadrilateral piece of bone, 4 cm. long, 2 cm. wide and 3 mm. thick, is removed from the tibia with a chisel or motor saw with its attached periosteum intact. The periosteum is stripped back from the anterior surfaces of the fragments of the patella a sufficient distance to allow bony contact with the flat surface of the transplant. The transplant is fitted across the line of fracture with its flat, cut surface in equal contact with each fragment. The fragments are united by a suture of kangaroo tendon which crosses in front of the transplant, holding it in place. The periosteum previously reflected from the fragments of the patella is sutured over the transplant. The fascia is brought together with chromicized catgut. The superficial parts are closed and the extremity is immobilized in plaster of Paris.

The flat, contact transplant is also applicable to repair of old fractures of the patella in which the fragments can be brought into apposition and securely retained by absorbable sutures. The contact transplant does not aid in the immediate retention of the fragments in apposition.

Rogers[16] reports a case of fracture of the patella in a man, aged forty-four years, produced by muscular violence. It was treated by external immobilization for six weeks. Fibrous union resulted. The fragments were separated one inch. There was a weak band of fibrous tissue connecting them (Fig. 131). The non-union was exposed and a transplant was grafted across the defect. It was taken from the internal surface of the tibia. It was one and one-half inches long, three-fourths inch wide and one-eighth inch thick. The ligamentum patella and the quadri-

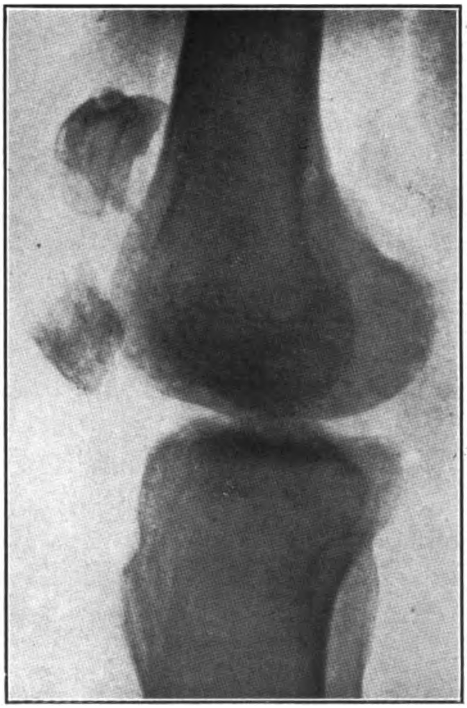


FIG. 131.—Ununited fracture of patella. (Rogers.)

ceps tendon were united by chromicized catgut over the transplant.

A röntgenogram, taken nineteen weeks after operation, shows the transplant grafted to the fragments and bony union between the fragments (Fig. 132).

2. The fragments may be dowelled together by diagonal peg transplants, as shown in the photograph of a prepared specimen (Fig. 133). The transplants cross each other at the line of fracture at different levels, holding the fragments in apposition. The fragments are approximated with a clamp while two drills are passed diagonally through them in different directions. The transplants are taken from the sharp edge of the tibia without periosteum. They are sawed

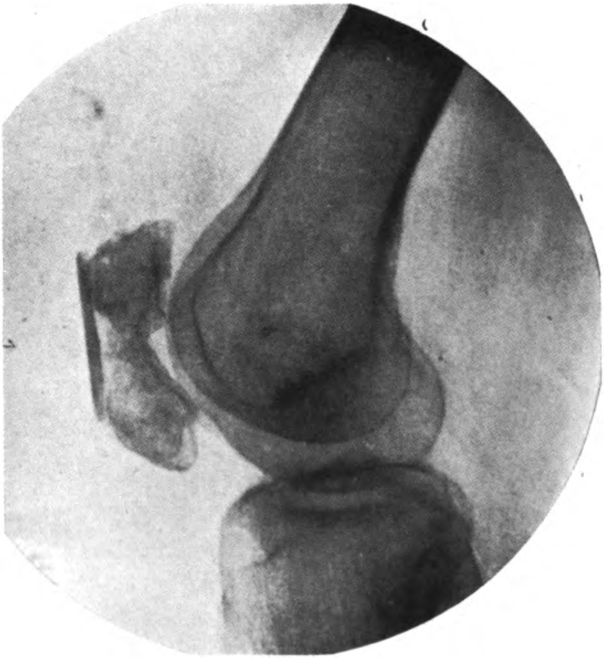


FIG. 132.—Röntgenogram, showing repair of ununited fracture of the patella by contact transplant, nineteen weeks after operation. (Rogers.)

quadrilateral in shape, approximately fitting the drilled holes. They must not be large enough to split either fragment when driven into position. One drill is removed at a time and a transplant is driven into its place, and then the other drill is removed and the second transplant inserted. The fragments are pinched together. The patellar ligament and tendon of the quadriceps extensor are sutured with kangaroo tendon and the wounds are closed. The extremity is immobilized with plaster of Paris.

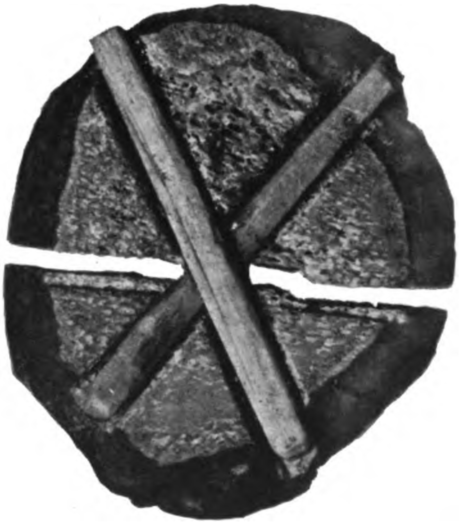


FIG. 133.—Section of prepared specimen, showing double-peg transplant in ununited fracture of the patella.

The repair of ununited fractures of the patella by the use of peg transplants is indicated where the fragments have retracted to such an extent that absorbable sutures alone are not sufficient to retain the fragments in apposition. This repair furnishes immediate support to the reduction. The peg transplants inserted at different angles prevent the fragments from being pulled apart. The transplants graft into the patella and form a strong bond of compact bone across the defect.

UNUNITED FRACTURES OF THE TIBIA.

UNUNITED FRACTURES OF THE SHAFT OF THE TIBIA. —The application of a cortical transplant is the operation of choice in the great majority of cases of non-union in the tibia, because: (*a*) the compact bone of the tibia is thick and strong; (*b*) the internal surface is flat and well adapted to receive a cortical transplant; (*c*) there is little tendency to displacement of the fragments; (*d*) the bone is superficial where its position is easily controlled by external immobilization; (*e*) the fibula usually has united and supports the tibia, making it impossible to introduce a medullary graft without refracture of the tibia and unnecessary operative traumatism. At this location the cortical transplant is superior to the medullary transplant because it does not require refracture of the fibula.

Non-union of the tibia following old infected compound fractures, with scarring and loss of substance, should not be subjected to autoplastic repair until the tissues are free from pyogenic germs and the danger of reëstablishing the infection has passed, requiring approximately three months after all active infection has subsided. The incision should avoid the scar tissue and expose the non-union by indirect incision.

In ununited fractures, the internal surface of the tibia is exposed by an incision placed so that it will not superimpose the transplant when the wound is closed. The soft tissues are thin at that location and slight gaping of the wound would expose the transplant. The periosteum over the fragments is incised longitudinally and reflected from the space required for the autoplastic repair. The ends of the fragments are cleared from interposing tissue and freshened and aligned if there is deformity. A gutter is outlined with parallel motor saws on the internal surface across the non-union extending into healthy bone 6 cm. or 7 cm. in each direction. The sides are sawed with a single saw, cutting on a bevel toward and into the medullary canal. The ends are cut with a small saw on a bevel toward the medullary cavity but away from the non-union. The transplant is outlined and removed by the same method used in cutting the gutter, so that the different bevels will fit the reverse bevels of the gutter. The periosteum is removed with the transplant and retained on it. The transplant is made enough longer than the gutter for the ends to be dovetailed tightly into the ends of the gutter after it is sprung into position. The transplant is tied into its bed by strands of kangaroo tendon passed through holes drilled at the sides of the gutter, and the periosteum of the tibia is sutured over all with catgut sutures. The superficial wound is closed, dressed and the leg immobilized in a circular plaster-of-Paris cast, including the foot and extending above the knee-joint. The immobilization is retained during solidification of the non-union which is usually secure in about eight weeks.

The medullary transplant is indicated in the tibia where there is non-union of both tibia and fibula. It is indicated where there is great angular deformity and it is evident that a cortical graft or wedge on one side will not be sufficient to remedy the deformity and secure alignment. It is necessary under these conditions to immobilize the repair by a cast in a position to prevent any tendency to reproduction of the deformity with pressure necrosis of the graft or recipient bone. If necessary, a contact graft can be applied to the non-union in the fibula.

The following history of a personal case illustrates the application of autoplastic bone repair and its efficiency in a severely comminuted and neglected ununited fracture of the upper part of the tibia in an old man:

CASE No. 24.—Ununited comminuted fracture of the tibia and fibula.—W. K.; German-American; laborer; aged fifty-one years; was struck on the shin by a motorcycle on September 7, 1914, breaking both bones of the left leg immediately below the knee.

Examination, one month after injury, showed a slender, delicate old man with a false point of motion in his leg. The left leg was 4 cm. shorter than the right. A röntgenogram revealed a severe comminuted fracture of the tibia and displacement of the small fragments and a simple fracture of the fibula (Fig. 134).

Operation for autoplastic repair was performed October 6, 1914. Incision showed the tibia to be badly comminuted, with fragments of bone lying diagonally between the ends of the main fragments, preventing coaptation. Very little attempt at callus formation had occurred. The fragments were prepared for the application of a medullary transplant. The upper end of the lower fragment of the fibula, 10 cm. in length, was stripped out of its periosteum and removed for the transplant. One end of this piece of fibula was forced into the medullary canal of each fragment of the tibia, crossing the comminuted area. Traction was made on the leg to relieve the shortening produced by the fracture and a fragment of bone was wedged between the ends of the tibia to maintain the length of the bone. After closing and dressing the wound, the leg was fixed with plaster of Paris in slight flexion to neutralize the action of the muscles. Immobilization was maintained for sixteen weeks, when solid union had occurred, at which time a röntgenogram showed abundant callus around the graft and ends of the fragments (Fig. 135).

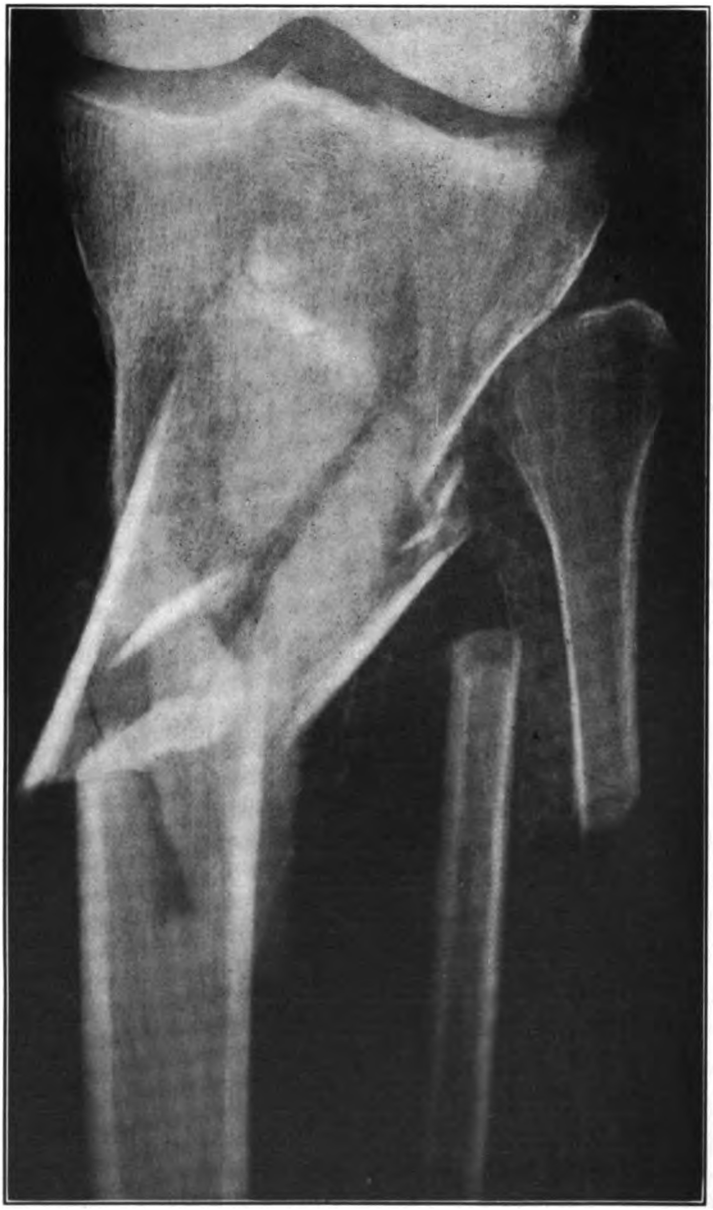


FIG. 134.—Case No. 24. Röntgenogram of ununited comminuted fracture of tibia and fibula.

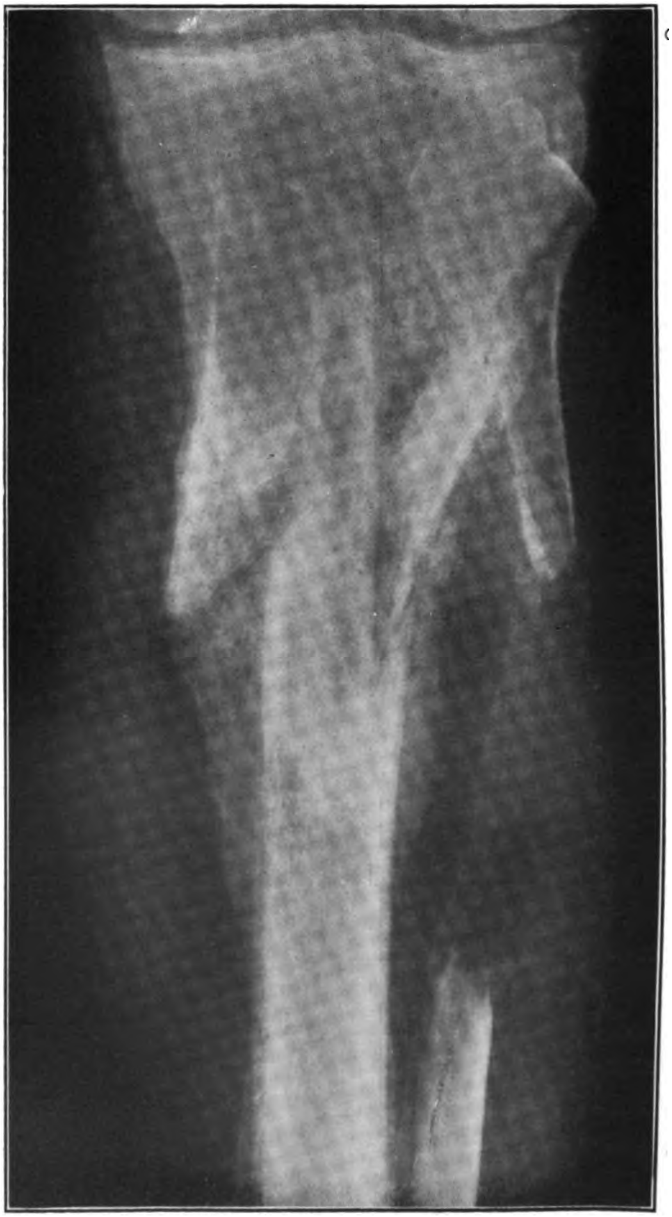


FIG. 135.—Case No. 24. Röntgenogram of repair of ununited comminuted fracture of the tibia by a medullary transplant taken from the adjacent fibula, four months after operation.

The following personal case illustrates the use of the cortical transplant in ununited spiral fractures of the tibia, after union of the fibula:

CASE No. 25.—Ununited fracture of the tibia.—P. K.; Polish-American; clerk; aged thirty-five years; sustained a fracture of both bones of the right leg in March, 1914. Treatment by external immobilization was followed by non-union of the tibia.

The patient was admitted to Cook County Hospital October 20, 1914. A röntgenogram showed an ununited spiral fracture of the lower third of the tibia. The fracture in the fibula had united (Fig. 136).

Operation for alignment and transplantation of bone into the ununited fracture was performed two weeks later. An incision over the deformity showed the fragments to be surrounded by a large amount of callus. There was a false point of motion in the tibia. The periosteum was incised and reflected. The tibia was sawed across at the defect. The fragments were placed in alignment without removing the callus. While the fragments were held in reduction, a gutter was cut across the defect through the cortex into the medullary canal. A transplant, to fit the gutter, 8 cm. in length and 1 cm. in width, was obtained from the spine of the tibia. It was removed from an area well above the sclerosis produced by the ununited fracture. The periosteum was retained on the transplant. The transplant was wedged into the gutter, fastened by strands of kangaroo tendon passed around the transplant and through holes drilled in the sides of the gutter. The reflected periosteum was sutured over the transplant. The wound was closed in the usual manner. The leg was immobilized in a plaster-of-Paris cast.

A röntgenogram, taken nine months after operation, shows solid bony union of the fracture (Fig. 137).

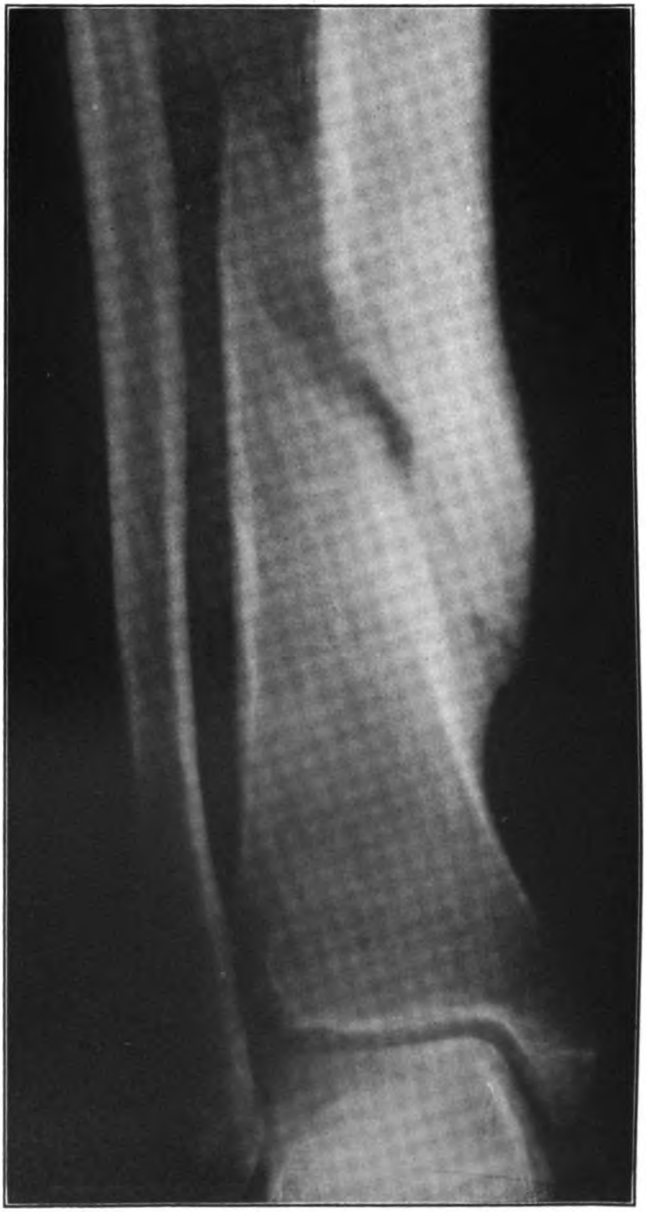


FIG. 136.—Case No. 25. Röntgenogram of ununited spiral fracture of the tibia with union of the fibula.

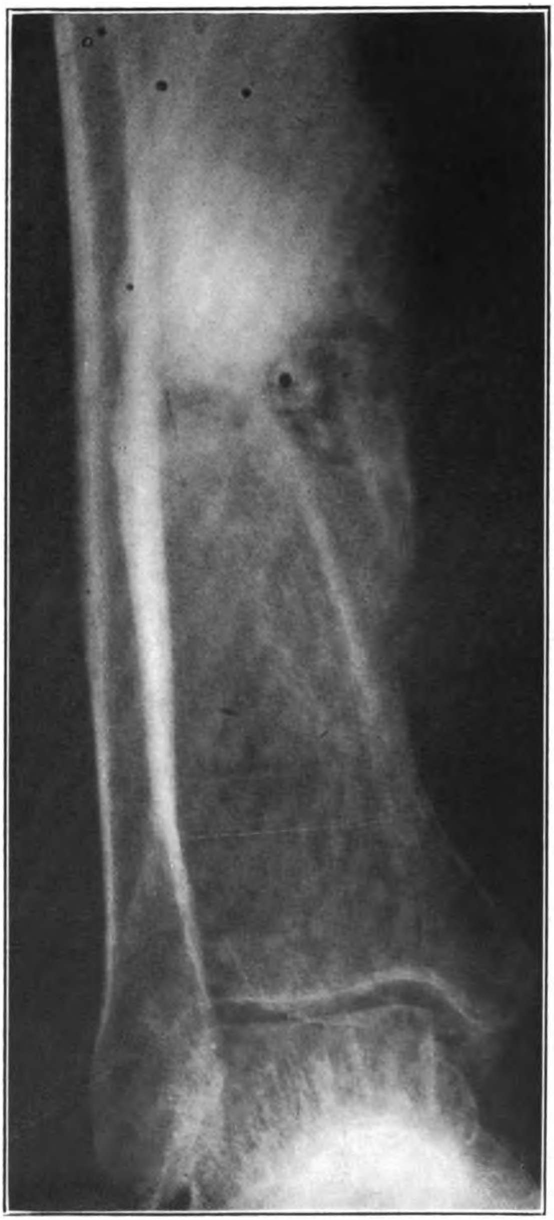


FIG. 137.—Case No. 25. Röntgenogram of ununited spiral fracture of the tibia, nine months after repair by a cortical transplant, showing bony union of the fracture.

UNUNITED FRACTURES OF THE BODY OF THE VERTEBRÆ.—When non-union occurs after fracture of one or more of the vertebral bodies without displacement or cord pressure, but accompanied by pain, discomfort and lack of support, Albee[17] recommends the use of a transplant grafted into the spinous processes of the fractured vertebra and into at least the spinous process of one uninjured vertebra on either side of the non-union to produce indirect ankylosis and support of the non-union.

After localization of the non-union by a röntgenogram, a curved incision is made exposing the spinous processes of the defective vertebræ and one or two spinous processes on either side. These spinous processes, with their attached ligaments, are split *en masse* with a thin chisel and knife, and the same side of each is fractured to form a gutter for the transplant.

A strong transplant is obtained from the tibia, long enough to overlap the prepared spinous processes. It is placed in the gutter as deeply as possible in bony contact with the split processes. The cleft is closed over it with interrupted kangaroo-tendon sutures.

The vertebral column is immobilized on a fracture bed or with a plaster-of-Paris cast for five weeks.

SUMMARY.

1. Autoplastic transplantation of bone is the operation of preference in ununited fractures.

2. The transplant, when properly applied with attention to the essential details of the operation, grafts to the fragments, bridges the defect and eventually causes osseous consolidation of the ununited fracture.

3. The osteogenetic activity in the ends of the fragments has diminished or ceased in ununited fracture. A transplant of fresh living bone, obtained from

beyond the area of sclerosis, furnishes the necessary osteogenetic stimulus to produce osseous union of the ununited fracture.

4. Infection is more likely to occur in autoplastic operations in ununited fractures than in recent fractures. Vital resistance and recuperative activity are below normal or there would not likely have been failure of union.

Ununited fractures frequently occur as a result of old compound fractures. Microörganisms are present in the tissues for a long period after healing by granulation in the presence of suppuration. Early operation in this class of ununited fractures predisposes to the reëstablishment of the infection.

CHAPTER VIII.

AUTOPLASTIC IMMOBILIZATION IN TUBERCULOUS SPONDYLITIS.

DESCRIPTION OF METHODS.

THERE are three recognized methods of indirect autoplastic immobilization of the bodies of the spinal vertebræ in tuberculous spondylitis. These methods depend upon anchoring the spinous processes either by grafting a transplant of live bone into the spines of the diseased and adjacent vertebræ or by fusing the spines into a continuous bony mass.

The method to be selected in the individual case depends upon the location of the disease, the size and shape of the kyphosis and the age of the patient.

The Hibbs operation is applicable to the dorsal or dorsolumbar region, especially in older children or adults. It is not applicable in very young children where the spinous processes are largely cartilaginous, because of the length of time required for the bony fusion to take place.

The Albee operation is applicable to any part of the vertebral column, except the cervical, to any size of kyphosis and to any age of the patient.

The Don operation is limited to the cervical region because of the anatomical shape, size and relation of the spinous processes of that location.

1. THE HIBBS OPERATION.[18]—This operation consists in producing a fusion of the posterior aspects of the vertebræ to prevent motion of the vertebral articulations in the diseased area and to prevent

pressure between the bodies undergoing tuberculous degeneration.

The operation is performed with the patient in the ventral position. A longitudinal incision is made, exposing the spinous processes, the periosteum is split and reflected back to the base of the transverse processes, denuding both the spinous processes and the laminæ, the spinous processes are broken at their base with a chisel and placed so that the tip of each one is in apposition to the broken base of the process immediately below it. The spinous processes of the tuberculous vertebræ and those immediately above and below are included in the operation (Fig. 138).

The periosteum is pushed back from the adjacent edges of the laminæ to their ventral side after its removal from their posterior surfaces. A small piece of bone chiselled from the laminæ is placed transversely across the space between them, its free end in contact with the laminæ next below.

The periosteum, supraspinous and interspinous ligaments are closed over the fragments by interrupted chromic catgut sutures, the superficial wound is closed and sterile dressings applied.

This operation induces a permanent callus, which binds together the fragments and the posterior parts of the diseased and adjacent vertebræ. It prevents motion in the vertebral articulations. It indirectly produces immobilization of the diseased vertebral bodies, relieving the symptoms and arresting the tuberculous disintegration.

The postoperative treatment consists in the application of a steel brace, absolute rest in bed for eight weeks, sitting up for four weeks, walking at twelve weeks, and gradual removal of the brace at sixteen weeks. This operation is of use especially in dorsal tuberculosis where the spinous processes are long and overlapping.

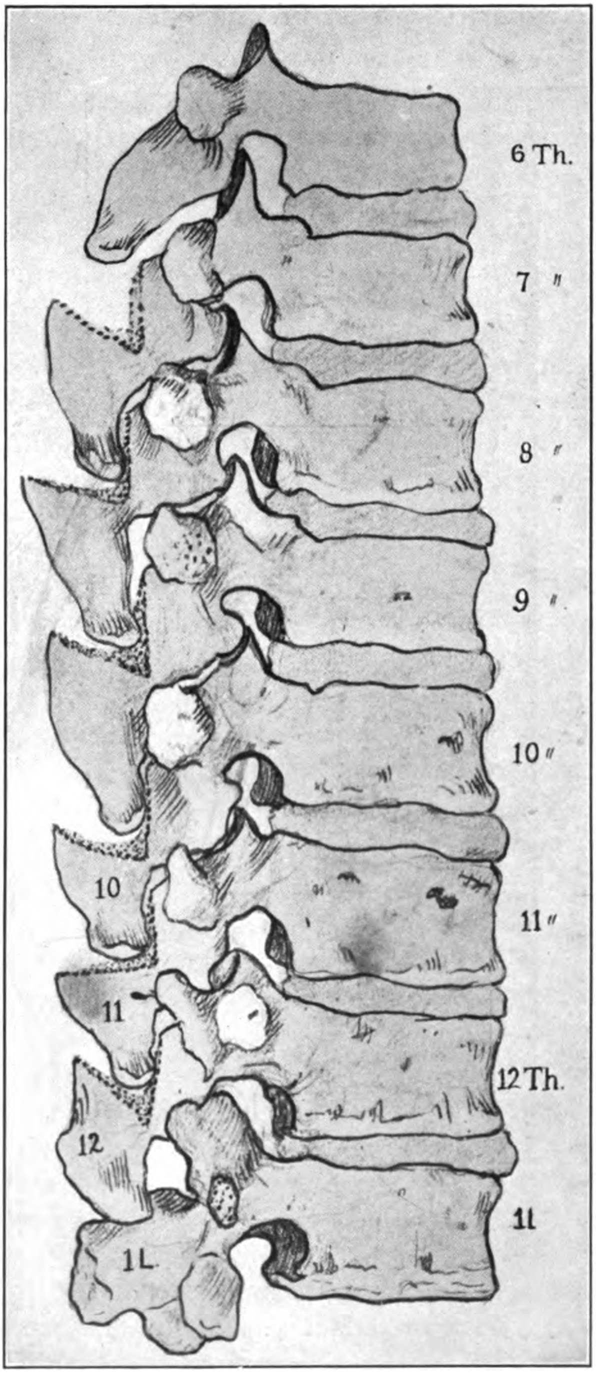


Fig. 138.—The Hibbs operation. Spinous processes partially fractured and used for bridging the gap between the vertebræ. (Hibbs.)

Hibbs reports a series of forty-three successful cases operated at the New York Orthopedic Hospital.[19]

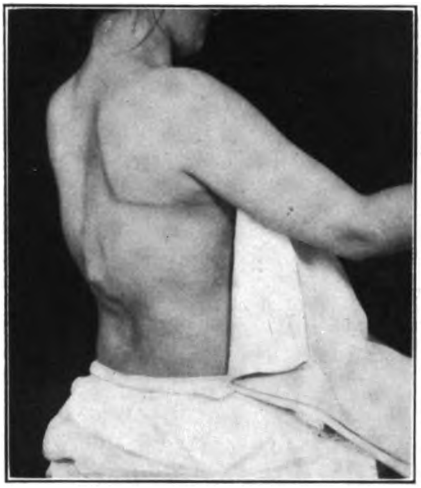


Fig. 139.—Photograph of case of dorsolumbar tuberculous spondylitis, before operation. (Hibbs.)

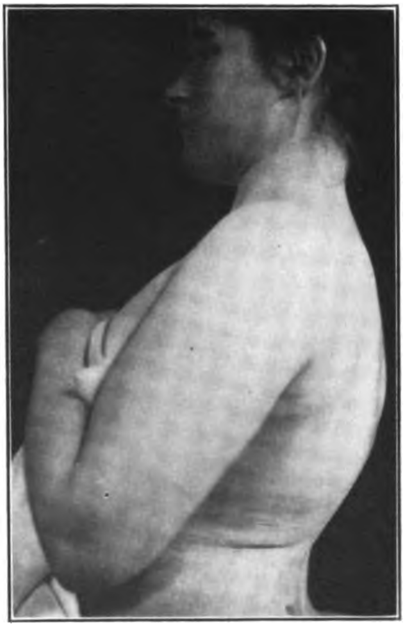


Fig 140.—Photograph of case of dorsolumbar tuberculous spondylitis, eleven months after operation. (Hibbs.)

He cites one case as a striking illustration of the results of the operation,[20] a woman of twenty-five, with very active tuberculous spondylitis complicated with a large psoas abscess. The kyphosis was marked from the ninth dorsal to the second lumbar (Fig. 139). The operation included four dorsal and three lumbar vertebræ. The psoas abscess was aspirated and did not return. Recovery from the tuberculous disease was apparently complete (Fig. 140). A röntgenogram showed continuous bone formation, fusing six vertebræ. With so long a segment immobilized, the freedom of motion was compensated above and below with almost no awkwardness.

2. THE ALBEE OPERATION.[21]—In this operation a transplant from the crest of the tibia is grafted into the tips of the spinous processes of the tuberculous vertebræ and into the processes of normal vertebræ above and below the lesion, producing indirect immobilization of the diseased vertebral bodies (Fig. 141).

With the patient in the ventral position, the spinous processes are exposed by a curved incision through the skin, fat and fascia, lateral to the spines so that the scar will neither superimpose the kyphosis, the grafted area, nor become adherent to the spines. The supraspinous and interspinous ligaments are divided and the spinous processes are split longitudinally with a thin, wide, surgical chisel in such a manner that when one side of each spine is broken over, it will leave a straight cleft or gutter to receive the transplant. If the tuberculous process is localized in the dorsal region, the gutter should include the spines of two normal vertebræ above and below the lesion. If the process is localized in the lumbar region, the inclusion of one vertebra above and one below the tuberculous area is sufficient. The gutter having been completed, hemorrhage is checked and the wound is packed with gauze wet in hot, normal salt solution, while the transplant is being obtained.

The transplant is taken from the crest of the tibia by means of a motor saw or chisel and should include the periosteum, cortical bone, endosteum and attached marrow. The length is determined by measurement across the spinous processes exposed in the gutter.

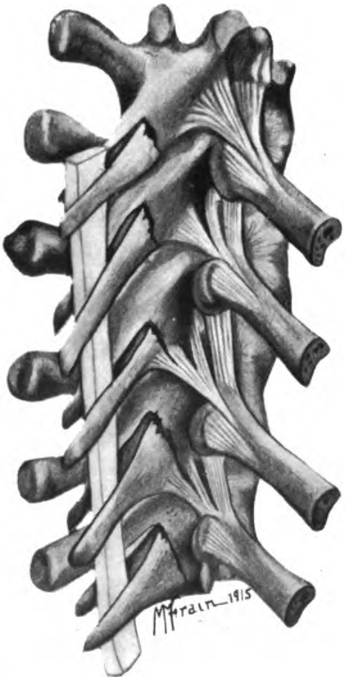


Fig. 141.—The Albee operation. A transplant between the split spinous processes.

The width should be from 7 mm. to 15 mm., according to the size and age of the patient. The thickness should be equal to the entire thickness of the cortex of the tibia. The transplant is fitted to the gutter so that it will contact with the split spinous processes. The nearer the end of the spines that the transplant is contacted, the greater the leverage on the bodies of the vertebræ. If the kyphosis is so great that a straight transplant cannot be properly imbedded and contacted to the split surfaces of the spines, it must be bent or shaped to fit over the irregularity. The transplant may be bent to fit the kyphosis by making transverse saw cuts on the endosteal side.

The transplant is placed in the cleft between the split spines and forced into the position of proper contact. The bent transplant is placed with the periosteal surface posteriorly. The straight and shaped transplants are placed edgewise in the gutter. The gutter is closed and the transplant secured in position by interrupted sutures of strong kangaroo tendon, introduced through the split supraspinous and interspinous ligaments. The ends of the transplant should be especially well secured. Small fragments of bone may be packed around them to produce quicker and stronger bony union with the spines. The skin and fascia are closed by catgut sutures, and the wounds dressed in the usual manner.

The postoperative treatment consists in confinement to a fracture bed from five to eight weeks, after which the patient is allowed to be up and about for a part of each day.

Cases with psoas abscess, cold abscesses or paraplegia, require longer treatment in the decubitus position, the length of time depending upon the condition and progress of the complications. The period of convalescence varies from three to eight months, depending upon the shape, strength and location of the transplant and the physical condition of the patient.

External, mechanical supports are not required except occasionally in severe cases of dorsal kyphosis, where the leverage is inefficient, because of the shape, position or application of the transplant. When properly applied, the transplant grafts to the spinous processes, producing permanent immobilization of the corresponding vertebral bodies, with consequent relief from pain and muscular spasm, and eventually arresting the progress of the tuberculous process with its associated kyphosis.

Series of cases operated by this method have been reported by Albee,[22] Ryerson,[23] Thomas,[24] Elmer,[25] Nutt[26] and many others. The general consensus of opinion seems to be that the operation has a distinct advantage over the expectant treatment by external immobilization, in that the symptoms are relieved more quickly and the patient can be up and about without supports, living a more normal life under better conditions, which tend toward more rapid cure of the tuberculous process in the vertebræ.

Albee's operation has been modified by Halstead,[27] of Chicago, who saws transversely through the spinous processes at their bases and inserts a flat transplant from the internal surface of the tibia between the cut surfaces of the divided spines. When the spines are replaced and sutured, the transplant is held firmly in position. The transplant grafts both to the spinous fragments and vertebræ, completely immobilizing the diseased segment of the vertebral column.

3. THE DON OPERATION.[28]—This operation consists in the immobilization of the cervical vertebræ, affected with tuberculosis, by bridging from the spinous process of the vertebra prominens to the spine of the axis with a transplant of living bone (Fig. 142).

An incision is made exposing the spinous processes of the cervical region. The periosteum is reflected from the spine of the seventh vertebra and from the base of the second. A section of rib, long enough to reach from the seventh to the second spine, is resected.

An opening is made in the wider end of the rib and fitted over the spinous process of the vertebra prominens. With the transplant in the gutter and the convexity forward, the opening is adjusted over the seventh spine. The neck is held in proper position while the rib is cut across so that it will fit into the groove at the base of the spine of the axis. The transplant is perforated at the upper end and sutured with kangaroo tendon to the interspinous ligament and the soft parts are closed over it.

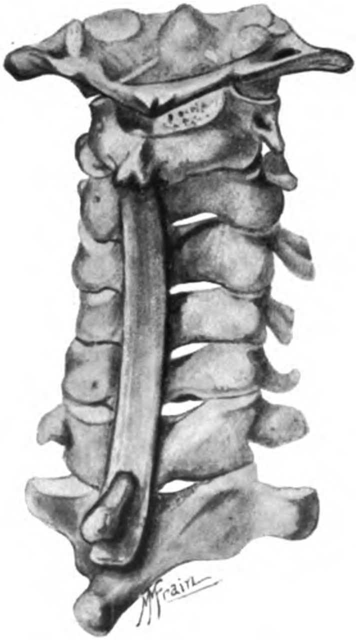


FIG. 142.—The Don operation. A transplant bridging from the spine of the axis to the spine of the vertebra prominens.

Don removes the periosteum of the rib and obtains successful results, but as the transplanted rib acts as a bridge across the diseased area, it would seem that the removal of the periosteum of the convex side, only at the points of bone contact with the denuded spines, would increase the viability and permanency of the graft.

The after-treatment consists of rest in bed with the neck supported by sand-bags until the patient can sit up without pain or discomfort. Mechanical supports are contra-indicated because of the discomfort to the patient and danger of displacing the transplant.

The transplant, by grafting to the spines at either end, produces indirect immobilization of the cervical vertebræ, which supports the head and gives relief from the pain and muscular spasm. The immobilization finally arrests the tuberculous disintegration.

Don reports the case of a boy of fourteen, who had been operated on one year previously for tuberculous glands of the neck. He came to the hospital with the symptoms of tuberculosis of the cervical vertebræ, including a retropharyngeal abscess which was drained. Three months later a röntgenogram showed tuberculous erosion of the bodies of the third and fourth cervical vertebræ. The boy would get up slowly, supporting the back of his head with both hands. He was operated on May 17, 1913, by the method described. He was put to bed with sand-bags supporting the neck. The patient was sitting up in five weeks, without complaint of pain, was walking ten days later, and has continued to have relief from all symptoms.

CHAPTER IX.

AUTOPLASTIC REPAIR OF CONGENITAL DEFECTS AND DEFORMITIES OF BONES.

1. SPINA BIFIDA.

THE autoplastic transplanation of bone to close the defect in spina bifida follows the control or replacement of the spinal hernia, preferably at the same operation.

At the operation the patient is placed in the ventral position with the head lower than the buttocks to prevent sudden drainage of the cerebrospinal fluid from the brain on puncture of the sac. A curved, transverse incision is made above the tumor as far as possible from the anus. The sac is exposed, separated from the surrounding tissues down to the defect in the bone, aspirated until collapsed and replaced within the cleft. The periosteum is reflected from the edges of the cleft and the surface of the bone freshened to receive the transplant.

The transplant may be obtained from the rib, scapula or tibia of the child. The bone for transplantation, retaining its periosteum, is procured and shaped by caliper measurements to cover the opening. It is applied so that the freshly cut, compact bone of the transplant is in apposition to the freshened edges of the cleft, completely covering the congenital defect. The periosteum previously reflected from the cleft is sutured to the periosteum of the transplant and the skin is closed by absorbable sutures.

The transplanted bone grafts to the edges of the cleft and seals the congenital opening into the neural canal.

A successful operation is reported by Trout,[29] in which a thin, flat transplant was obtained from the shin of the father and grafted over the defect (Figs. 143 and 144).

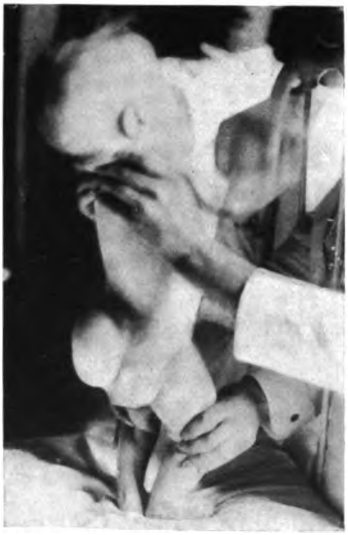


FIG. 143

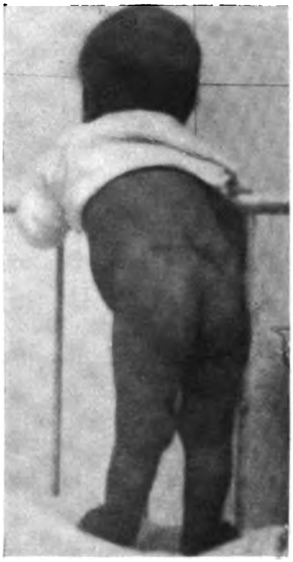


FIG. 144

FIG. 143.—Photograph of child with spina bifida before operation.

FIG. 144.—Photograph of child four months after operation for spina bifida. (Trout.)

A case is reported by Albee,[22] in which transplantation was done to remedy weakness and deformity after a previous operation on the spinal tumor.

2. CONGENITAL DISLOCATION OF THE HIP.

Autoplastic remodelling of the upper rim of the acetabulum (Fig. 145) by bone grafting, with reconstruction of the overstretched capsule, has been suggested as a remedy for intractable congenital dislocation of the hip-joint.[22]

A curved transverse incision is made, exposing the greater trochanter. The trochanter is sawed across and, together with its attached muscles, is reflected upward, exposing the dislocation.

With a thin chisel, the upper rim of the acetabulum is incised down to the cartilage, extending 12 mm. to 15 mm. back from the edge on each surface, and the rim is broken over toward the joint. The space thus opened is filled by transplants of a size to exaggerate the rim of the acetabulum sufficiently to hold the head of the femur in place (Fig. 146).

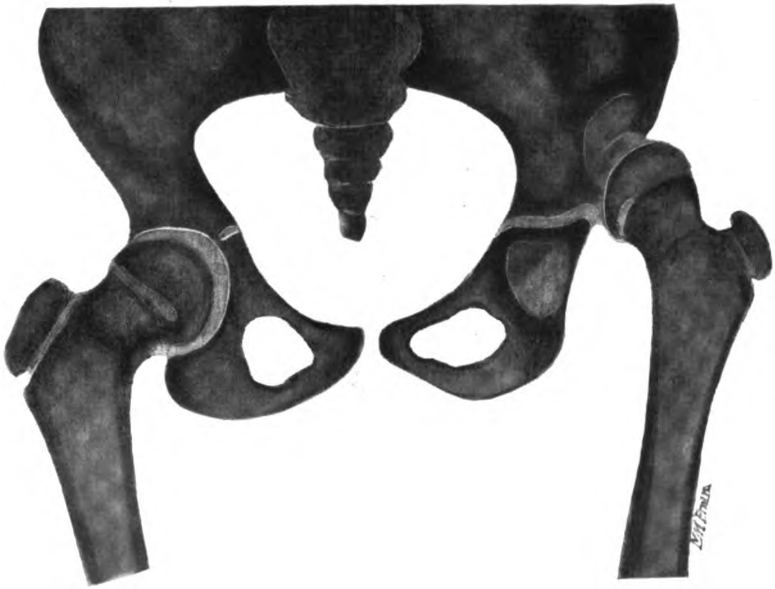


Fig. 145.—Röntgenogram drawing of congenital dislocation of the hip in a girl, aged ten years.

Wedge-shaped transplants are taken from the surface of the femur, which was sawed across in reflecting the trochanter. These are fastened in the incision in the rim of the acetabulum by kangaroo-tendon sutures.

The redundant capsule is reduced to the proper dimensions by reefing and plication.

The trochanter is replaced and secured by sutures or bone pegs and the wound closed by absorbable sutures. The joint is immobilized by a plaster-of-Paris spica, extending from the axilla to the toes in the position of flexion, external rotation and extreme abduction of the thigh. The immobilization should be retained for twelve weeks without change, after which the position of abduction may be modified and the fixation continued for at least three months longer.

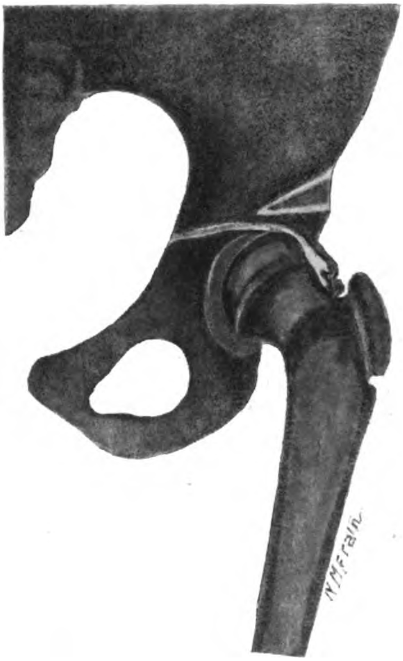


FIG. 146.—Location and shape of transplants required to remodel the rim of the acetabulum in congenital dislocation of the hip.

3. TALIPES EQUINOVARUS.

Autoplastic remodelling of the tarsal bones in certain severe forms of neglected or relapsing congenital club-foot in adults or older children has been suggested by Albee.[22]

Where the inner side of the foot is concave and short, and the whole foot underdeveloped, the grafting of a wedge of bone into the scaphoid will aid in remedying the adduction deformity, elongating and reshaping the foot (Fig. 147).

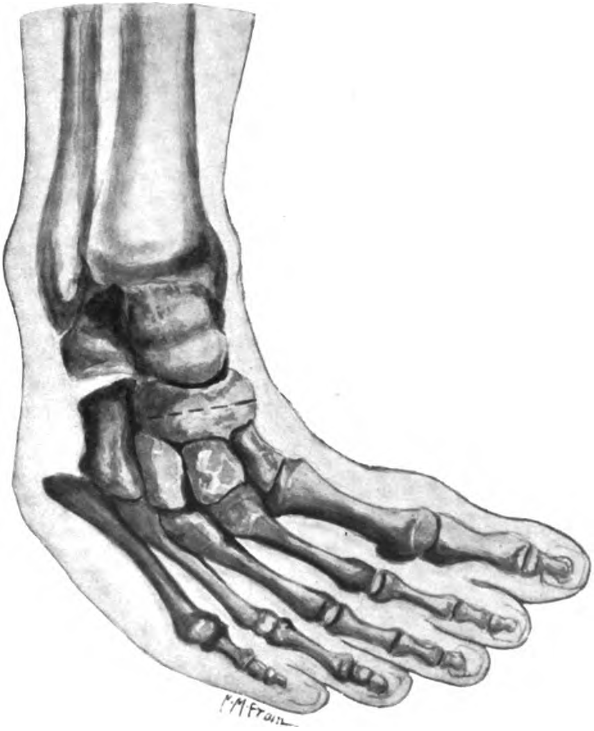


FIG. 147.—Talipes equinovarus with serious bony deformity, showing line of incision in the scaphoid.

The deformity of adduction is remedied by the size and shape of the wedge of bone transplanted into the scaphoid. The varus deformity is corrected by readjustment of the planes of the halves of the scaphoid. As a preliminary to the bone operation, tenotomy of the tendo Achilles is done and the equinus deformity remedied. A curved incision on the inner side of the foot exposes the scaphoid. It is divided with a wide surgical chisel and the adduction and varus deformities forcibly overcorrected, leaving a cleft between the fragments of the scaphoid (Fig. 148).

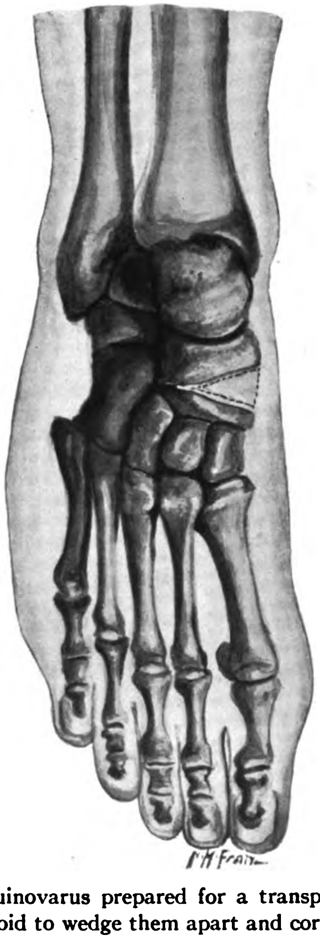


FIG. 148.—Talipes equinovarus prepared for a transplant between the segments of the scaphoid to wedge them apart and correct the deformity.

A wedge-shaped transplant, slightly larger than the cleft in the scaphoid, is taken from the tibia. It is forced into the cleft and secured to the scaphoid by sutures of kangaroo tendon passed through holes drilled in each. If the cuboid is greatly hypertrophied, the wedge-shaped transplant may be taken from it and transferred to the cleft in the scaphoid, straightening and rotating the foot, but not elongating it.

With the foot overcorrected and the knee flexed, the extremity is immobilized in plaster of Paris for eight weeks.

4. NASAL DEFORMITIES.

Autoplastic remodelling of the nose to relieve congenital deformities may be done along the same lines as for acquired deformities.

5. CRANIAL DEFECTS.

The transplantation of bone to close congenital cranial defects is effected along the same lines as required for the closure of acquired defects, with the exception that the dura mater has not been disturbed in the congenital form. Periosteum is not required on the under surface of the transplant, permitting a greater range of selection of bone for transplantation.

Schrager[30] successfully operated upon the following case, with a large, congenital cranial defect:

Case No. 26.—Congenital defect of the skull.—M. G.; American; aged seventeen years; clerk; was born with a defect of the right frontoparietal region.

Examination showed a defect, nearly circular in outline, 6.5 cm. in diameter (Fig. 149). The skin covering the defect was thinner than normal. There was a slight protrusion at the defect. There was strong pulsation over the area.

The patient had a morbid fear of being injured at the site of the defect and for this reason submitted to operation.

The defect was exposed by a horseshoe incision. A rabbet was cut into the rim of the defect. A pattern was taken with gutta-percha tissue. A separate incision was made over the parietal bone of the same side and a transplant outlined with the pattern. With angular chisels, the external table of the parietal bone, including periosteum, was removed and applied to the defect. The edges were adapted to the rabbet in the edges of the defect. The wounds were closed with waxed silk. The head was tightly bandaged. At the end of two months the transplant had grafted solidly into the defect, fulfilling the function of bony protection to the brain (Fig. 150).

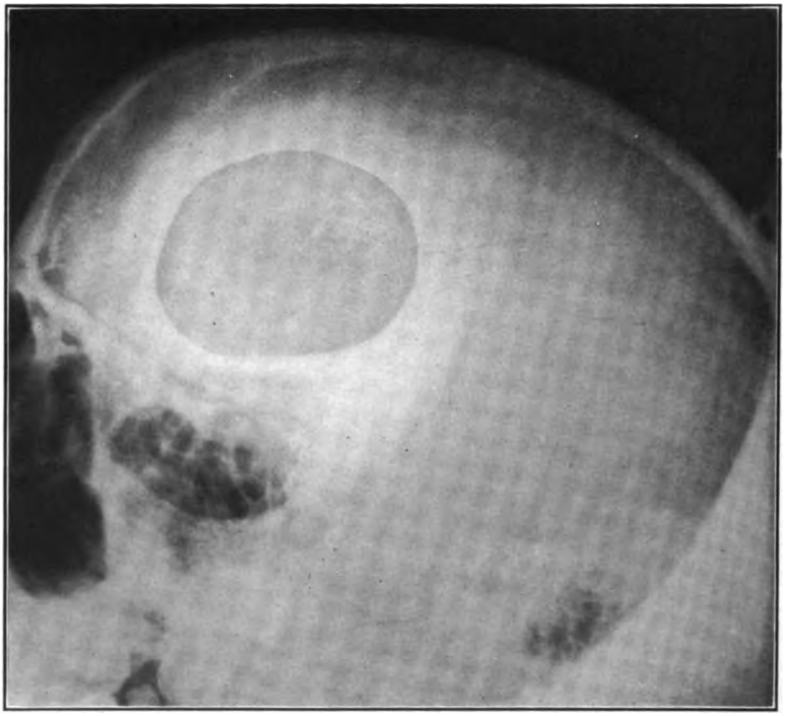


FIG. 149.—Case No. 26. Röntgenogram of congenital cranial defect. (Schrager.)

6. DEFICIENCIES OF LONG BONES.

Deficiences of long bones caused by incomplete fetal development should be supplied with the necessary bone by autoplastic transplantation to fill the deficiency, bridge the defect and reshape the deformed bone. The methods used for the replacement of bone in acquired defects of the same location should be followed.

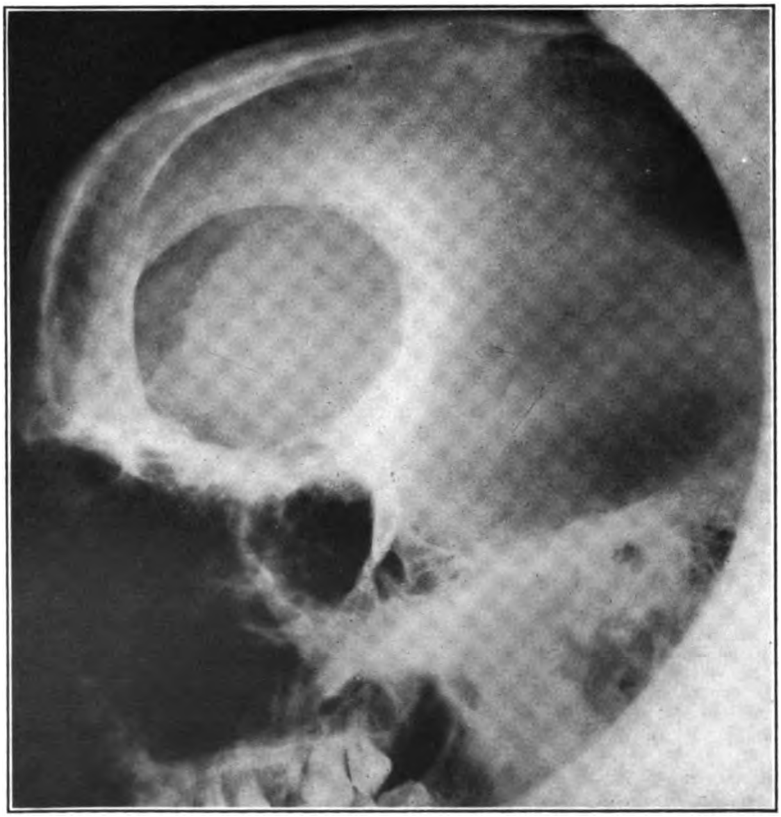


FIG. 150.—Case No. 26. Röntgenogram of repair of congenital cranial defect, two months after operation. (Schrager.)

CHAPTER X.

AUTOPLASTIC REPAIR OF ACQUIRED DEFECTS AND DEFORMITIES OF BONES.

1. DIAPHYSIAL DEFECTS.

In autoplastic transplantation to fill large defects in the long bones, produced by mutilating accidents or operations for the cure of osteomyelitis, tuberculosis or neoplasms of bone, the fibula is the best bone to use, except possibly in the tibia. It furnishes a very satisfactory bone unit which is easily obtained, while its loss from its normal location is not of great importance. A segment of its full thickness, somewhat longer than the defect is taken, the ends are fitted into the medullary canals of each fragment and wedged or dovetailed into position.

The use of nails, wire or other non-absorbable foreign material, to fasten the transplant into its new position, is contra-indicated, as it encourages infection, interferes to a certain extent with the grafting between the transplant and the fragments, and inhibits the subsequent hypertrophy of the transplant in its new location.

The periosteum is retained on the fibular transplant, except at the ends, where it is removed to obtain bone-to-bone contact with the host fragments. While grafting is taking place, the extremity is immobilized so completely that there shall be no motion between the transplant and recipient fragments.

Gangolphe and Bertein[31] have reviewed the work of this character to June, 1914, tabulating 47 cases of transplantation of the fibula into large defects of both the upper and lower extremity, with very encouraging results. Transplantation was done in 20 cases on account of osteosarcoma, of which 5 were of the humerus, 5 of the femur, 4 of the ulna, 4 of the tibia, and 2 of the radius; 5 for old, infected compound comminuted fractures; 21 for osteomyelitis of the tibia, and 1 for syphilis of the tibia.

Transplants taken from the crest of the tibia are used to fill small defects and by some operators are used to close defects of all sizes in the continuity of long bones. As much periosteum as possible is always carried with the tibial transplant.

Under favorable conditions the transplant, from whatever source obtained, grafts to the recipient fragments, becomes an integral part of the skeleton and hypertrophies according to the functional demands put upon it with its new conditions and environments.

DIAPHYSIAL DEFECTS OF SPECIAL BONES.

HUMERUS.—Autoplastic repair for deficiencies of the diaphysis of the humerus is required after recovery from old, mutilating injury or after resection of bone on account of osteosarcoma.

For transplantation to fill in the defect in the humerus caused by an old mutilating injury, an incision is made along the outer side of the arm, exposing the defect in the bone. The medial ends of the remaining fragments are developed and cleared of fibrous tissue. The medullary canal of each is reopened, with a reamer, well into healthy marrow. A transplant is obtained from the middle of the fibula, long enough to fill the defect and wedge 3 cm. or 4 cm. into each of the recipient fragments, or into healthy bone and marrow. The wound is closed in layers by absorbable sutures, obliterating all dead spaces, dressed with sterile gauze, and the arm padded and immobilized against the thorax by plaster of Paris, to remain without change until solid grafting has occurred.

Transplantation of bone should follow as a final step in the operation, when a complete segment of the diaphysis has been resected for osteosarcoma or other neoplasm. The fibular transplant should be wedged into position and the detached tendons sutured to the periosteum of the transplant.

Autoplastic transplantation to remedy the defect caused by resection of a neoplasm at the middle of the diaphysis of the humerus is well illustrated by a case reported by Gask.[32]

A boy, eleven years of age, came under observation with a chondrosarcoma of the left arm which had been growing one year. The tumor was a little above the middle of the arm, two and one-half inches in length and one and one-half inches in width.

At the operation, three inches of the diaphysis of the humerus was resected with the tumor, and the defect was bridged by a fibular transplant, which was wedged into the medullary canal of each fragment. The periosteum covering the segment of the humerus was removed with the tumor, but the periosteum of the segment of the fibula was retained and transplanted with it.

A röntgenogram, taken three months after operation, shows the transplant grafted into both fragments of the humerus. New bone can be seen extending the whole length of the transplant (Fig. 151). A röntgenogram, taken six months after operation, shows the transplant grafted into position, continuous with the shaft of the humerus, and the defect practically obliterated by hypertrophy of the transplanted bone (Fig. 152).

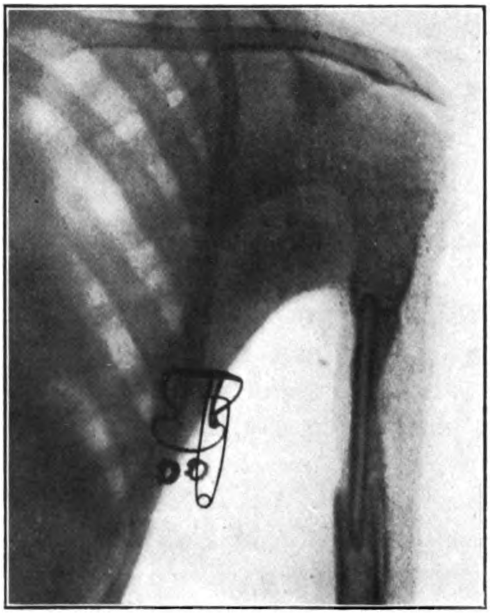


FIG. 151.—Röntgenogram of autoplastic repair of humerus by a fibular transplant, three months after operation following resection for chondrosarcoma. (Gask.)

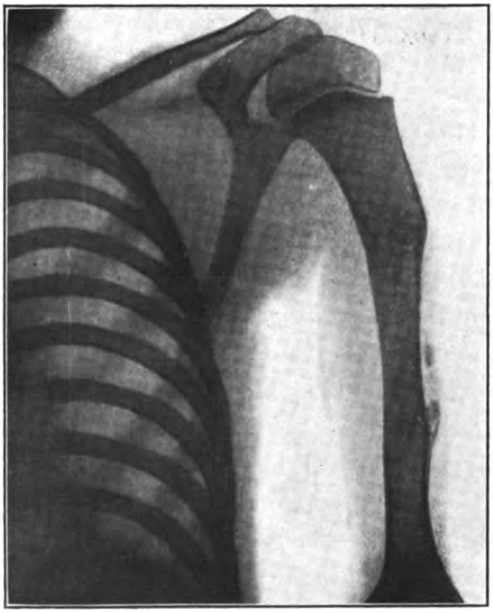


FIG. 152.—Röntgenogram of autoplastic repair of humerus, six months after operation. (Gask.)

In seventeen and one-half months the arm was apparently as good and strong as the other arm.

Radius and Ulna.—Autoplastic repair of a material deficiency of the diaphysis of the radius or ulna may be accomplished by the use of a transplant taken from the fibula or from the crest of the tibia, depending upon the condition of the fragments of the deficient bone.

Every effort should be made to secure the transplant in position by wedging, dovetailing and absorbable sutures, avoiding the use of wire and nails. The fibula, radius and ulna are nearly the same size, so that the fibular transplant cannot be wedged entirely into the medullary canal of the defective bone. The ends of hollow bones of nearly the same size can be trimmed in an oblique manner to form a wedge joint, the obliquity of each bone entering the medullary canal of the other, so that, as the bones are pushed together, the wedge joint fits more firmly (Fig. 153). With this technic a fibular transplant may be fastened firmly into a defect in the radius or ulna.

Transplantation is performed for deficiencies of the radius or ulna, due to accidental mutilating injury or operations for the removal of neoplasms of bone. A posterior incision is made, exposing the deficient bone, the ends are developed and freed from fibrous tissue, the fibular transplant is wedge jointed to the fragments and placed in position, the muscular attachments are secured to the periosteum of the transplant and the wound closed. The extremity, held at a right angle, is immobilized to the body, with the forearm midway between pronation and supination. It is retained in that position until the transplant has grafted firmly into its new location.

Janeway[33] transplanted bone from the crest of the tibia to fill a defect caused by the resection of five and one-half inches of the shaft of the left ulna, for chondrosarcoma in a middle-aged woman. He used

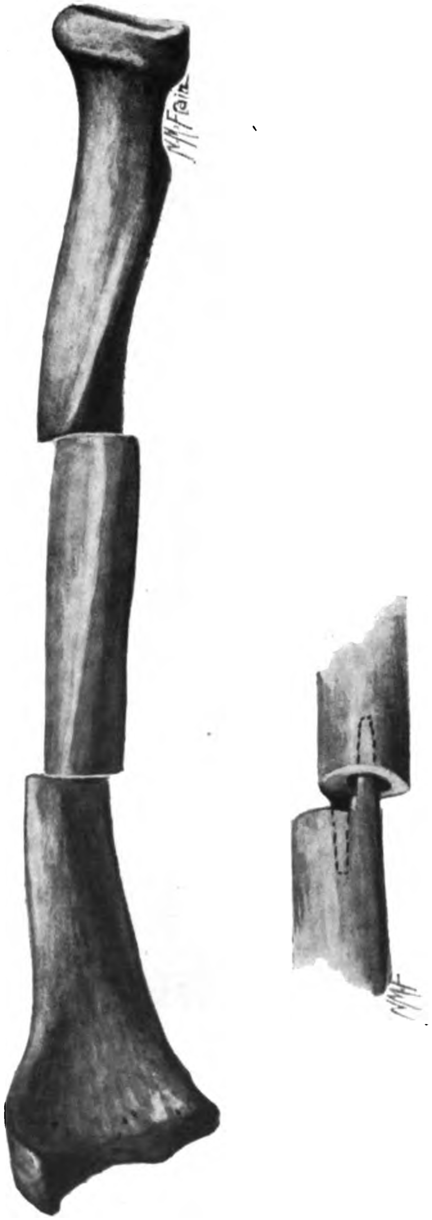


FIG. 153.—Wedge joint between bones of the same size.

a transplant chiselled from the crest of the tibia, of the same length as the defect, three-eighths of an inch wide and one-eighth of an inch thick, consisting of cortical bone and its adherent periosteum. The transplant was fastened to the fragments of the ulna by silver wire. The periosteum of the transplant was sutured to the periosteum of the ulna.

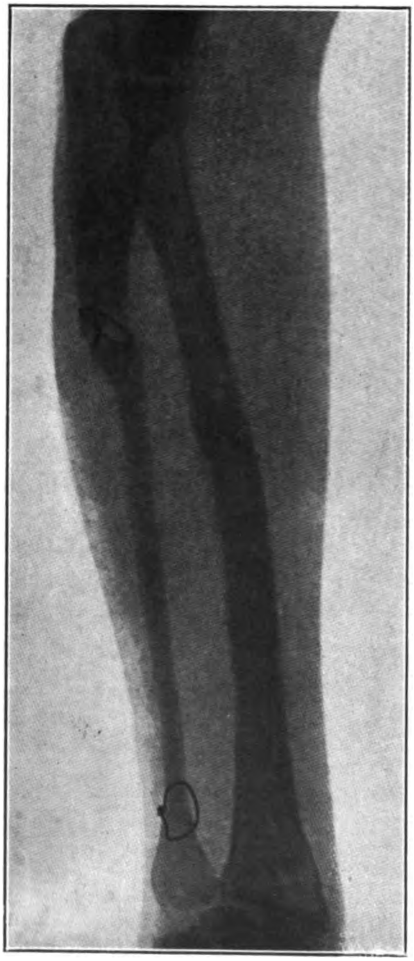


FIG. 154.—Röntgenogram of autoplastic repair of ulna after resection for chondrosarcoma, fourteen months after operation. (Janeway.)

The functional recovery was good, the patient being able to wash clothes at a tub, using the arm freely, in two months. A röntgenogram, taken fourteen months after operation, shows that the transplant has grafted into the ulnar defect and had undergone hypertrophy to meet the functional requirements of its host (Fig. 154).

PHALANGES AND METACARPALS.—The long bones of the hand are subject to the same diseases and conditions which cause destruction of bone in the larger long bones and the same principles apply to their repair.

An incision is made over the dorsal aspect of the bone at the defect, the tendons are separated and retracted, the diseased bone exposed and excised. A small tibial transplant, covered on two sides by periosteum, is secured and fitted to the medullary canals of the fragments of the defective bone. The periosteum of the transplant is sutured to the periosteum of the fragments and the wound closed by absorbable suture. The hand is immobilized by plaster of Paris over an indoor baseball of the proper size, which shapes the curve of the repaired bone to that of those immediately adjoining.

Haas[34] resected a portion of the diaphysis of the basal phalanx of the ring finger in a woman aged twenty-three years and transplanted bone from the tibia into the defect (Fig. 155). The anatomical and cosmetic results were good (Fig. 156) but there was considerable limitation of function due to the stiffness of the joints from prolonged immobilization.

FEMUR.—Autoplastic repair of the femur following resection of the diaphysis for malignant or benign disease may be accomplished by transplantation of a segment of the fibula into the defect.

Incision on a line between the greater trochanter and the external condyle exposes the diseased area of bone. The tumor is excised, the resulting defect and the medullary canal of the fragments are measured. A transplant is secured from the fibula of sufficient length to bridge the defect and to reach into the medullary canal of each fragment a sufficient distance to wedge the parts solidly together. The transplant is forced into position and the wound closed in a manner to obliterate all dead spaces. The repair is immobilized with a plaster-of-Paris cast extending from the axilla to the toes and including the opposite thigh, with the transplant and femur in the same axis, so that there is no leverage between them and

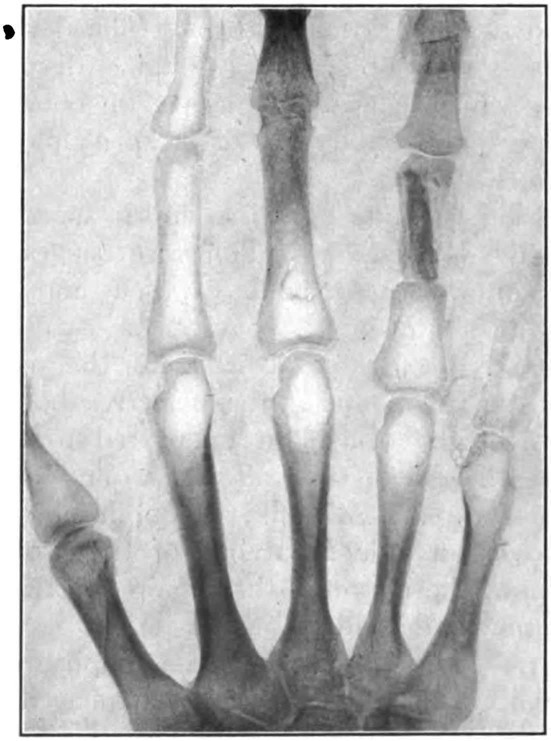


FIG. 155.—Röntgenogram of autoplastic transplantation of bone into a defect in a phalanx, two weeks after operation. (Haas.)

with the femur in a position of neutral muscular traction.

Poor results have so far followed transplantation of large segments of bone into the femur; the segment uniting to one fragment and a pseudarthrosis forming at the other.[31] This condition probably has resulted from imperfect immobilization and uncontrolled muscular traction, both difficult to avoid in any operation upon the femur.

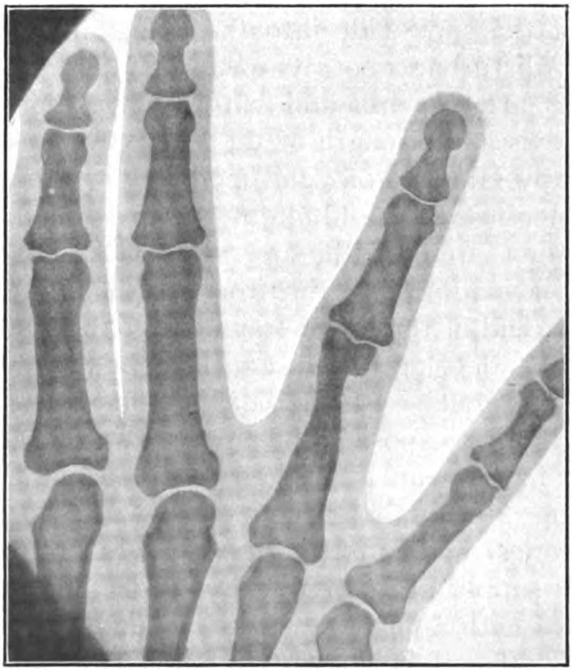


Fig. 156.—Röntgenogram of repair of phalanx, three months after operation. (Haas.)

Tibia.—A large number of cases of autoplastic transplantation of bone into large defects in the tibia, with excellent anatomical and functional results have been reported.

Defects requiring transplantation *en masse* are more common in the tibia than in other bones. The tibia is affected with the same diseases as other bones and is the bone of all others in which recovery occurs from acute infectious osteomyelitis, with conditions favorable for repair by transplantation of bone.

There are two methods of repair of large gaps in the diaphysis of the tibia when regeneration has failed after injury, osteomyelitis or other disease.

1. The transference of a central segment of the fibula of the same side into the defect in two steps, without disturbance of its own vascular supply or muscular attachments and with preservation of the normal axis and strength of the ankle-joint, as recommended by Huntington[35] and modified by Stone.[36]

Transference of the fibula at the upper end is done at the first step of the operation. A longitudinal incision is made along the front of the leg exposing the lower end of the upper fragment of the tibia. The fragment is developed and a socket cut for the reception of the fibula. An incision is made on the outer side of the leg exposing the upper part of the fibula and the muscles are separated along the interosseous membrane, until the two incisions are connected. The peroneal and anterior tibial nerves and nutrient vascular supply are carefully avoided. The fibula is cut across with a Gigli saw at a higher level than the defect in the tibia to obtain sufficient length for insertion into the socket prepared for it without shortening the leg. The periosteum is stripped back from that part of the fibula which is to be buried in the tibia, so that there will be direct bone apposition. The remaining periosteum and the muscular attachments are carefully preserved. The leg is sharply abducted until the angulation allows the end of the fibula to enter the socket in the fragment of the tibia and, as the extremity is aligned, the fibula is forced into position. The periosteum of the fibula is sutured to that of the tibia over the repair. The dead spaces are obliterated by intermuscular suture. The wounds are closed and dressed. The leg is immobilized in normal alignment and rotation by a circular plaster cast, which is retained until solidification has occurred and until the second step of the transference.

The second step of the operation consists in the alignment of one-half of the fibula with the lower fragment of the tibia to maintain the strength of the ankle and prevent varus deformity. A longitudinal incision is made, exposing the outer part of the lower epiphysis of the tibia. A small socket is made in the tibial fragment for the reception of one-half of the fibula when transferred. The fibula is exposed by dissection through the same incision and is split anteroposteriorly, including the periosteum, by a chisel or motor saw, for 8 cm. or 10 cm. At the lower end of the split, the inner half is cut across transversely at the level of the bottom of the socket in the tibia. The outer portion of the fibula is cracked at the upper extremity of the split,

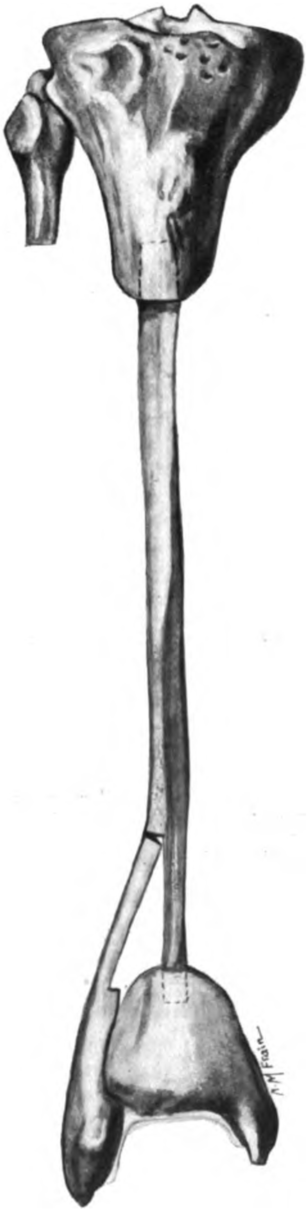


FIG. 157.—Transference of fibula into defect in tibia.

without tearing the periosteum. The inner part of the fibula is sprung into the socket prepared for it in the tibial fragment, where it is retained by muscular action (Fig. 157). The extremity is again immobilized in plaster until solid union occurs.

The fibula hypertrophies and furnishes a functionally efficient support for weight-bearing. The inverted Y arrangement of the lower end of the fibula retains the axis of the leg over the ankle-joint and prevents inversion of the foot. In children the growth in length depends upon the condition of the epiphyses of the tibial fragments.

In Stone's case the boy was able to walk without support or restraint at nine and a half months from the first operation (Figs. 158 and 159).

2. The transplantation into the fragments of the tibia of a long, slender piece of fresh bone from the crest of the opposite tibia.

A flap incision is made over the site of the defective tibia and the ends cleared from cicatricial tissue. A socket is made in either end for the reception of the transplant. The sockets should be made in the medullary canals when possible, otherwise slots can be cut in the cortex of the fragments. The transplant is obtained with periosteum attached to two sides. It is placed in position bridging the defect. It is secured to the tibial fragments by position, dovetailing, wedging and absorbable sutures, wire and nails only being used as a last resort. The wound is sutured in layers, dressed, and the extremity immobilized. Immobilization is continued until solid union has occurred between the transplant and the tibial fragments.

The transplant grafts into position, hypertrophies under the stimulus of function and eventually becomes an efficient weight-bearing bone.

This operation has the advantage of simplicity, with apparently quite as good results as in transference of the fibula. In one of Oechsner's cases,[37] in a child, the transplant hypertrophied to a size larger than the fibula in eleven months (Figs. 160 and 161) and the leg maintained a normal growth in length.

The following personal case illustrates the use of tibial transplants to fill defects in the shaft of the tibia:

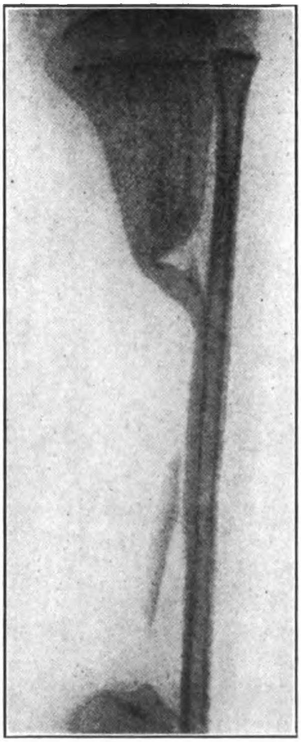


FIG. 158

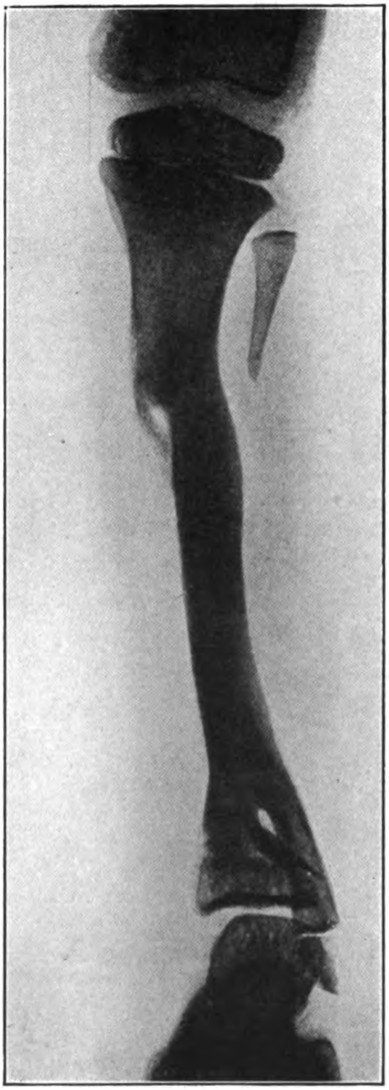


FIG. 159

FIG. 158.—Röntgenogram of defect in the tibia. (Stone.)

FIG. 159.—Röntgenogram of transference of fibula to replace the shaft of the tibia, two years and eight months after operation, showing marked hypertrophy of the transplanted fibula. (Stone.)

CASE No. 27.—Defect in the diaphysis of the tibia.—A. L.; Polish Jew; clerk; aged twenty-four years; received a compound comminuted fracture of both bones of the left leg, in a collision with an automobile, while riding a motorcycle. A segment of the full thickness of the tibia, 12 cm. in length, was entirely separated from its periosteum. The fragment was replaced and wired in position. The wound healed and remained closed for several months, after which it began to suppurate. Union of the fracture had not taken place.

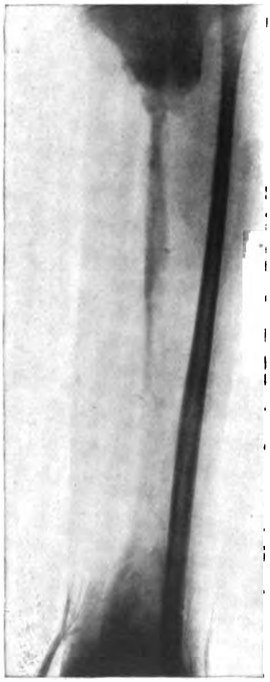


FIG. 160

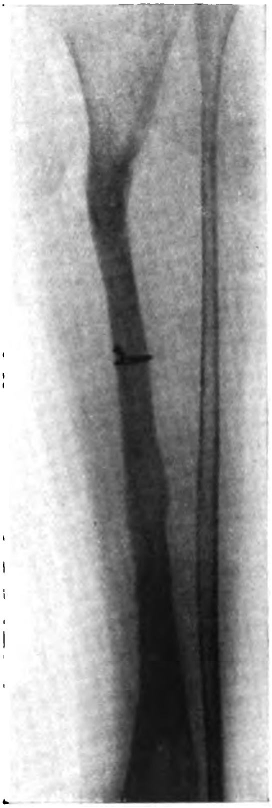


FIG. 161

FIG. 160.—Röntgenogram of defect in tibia from osteomyelitis. (Oechsner.)

FIG. 161.—Röntgenogram of a tibial transplant grafted into a defect in the opposite tibia, one year after operation. (Oechsner.)

Ten months after the injury a röntgenogram revealed necrosis of the intermediate fragment. The

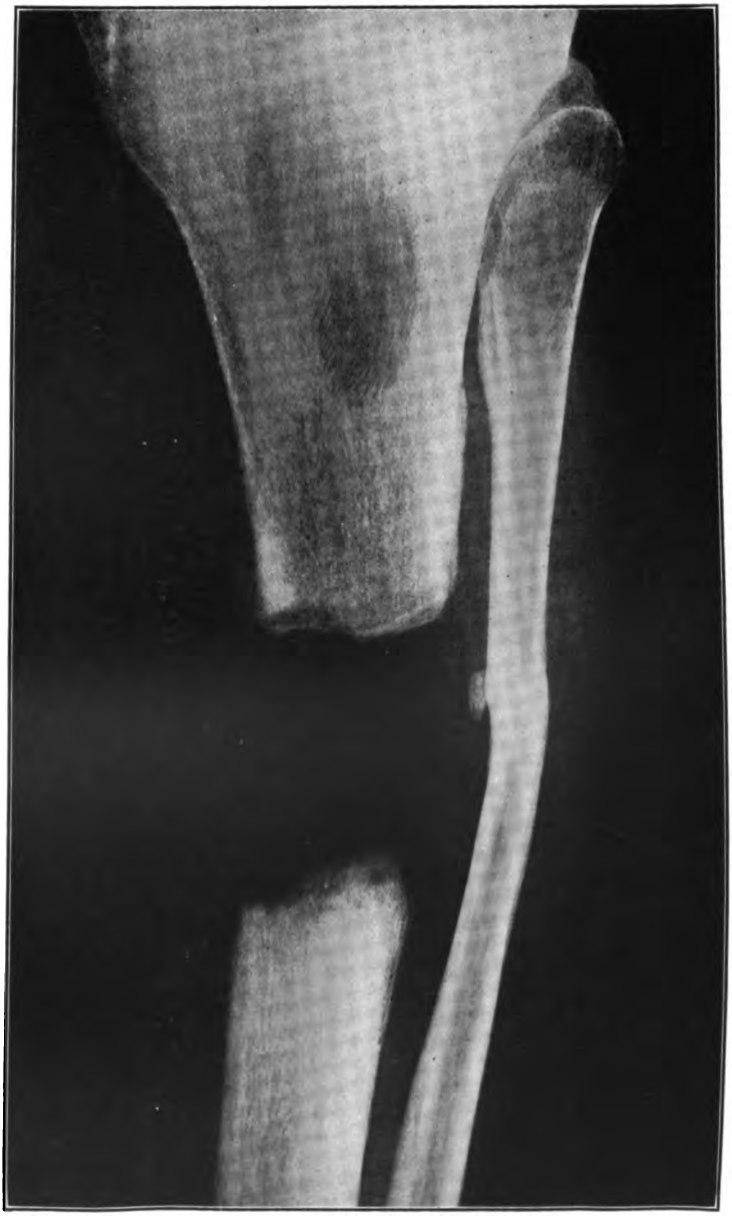


Fig. 162.—Case No. 27. Röntgenogram of defect in the tibia, from old compound comminuted fracture.

fragment and a large amount of infected callus were removed. The wound healed rapidly and was entirely closed in two months.

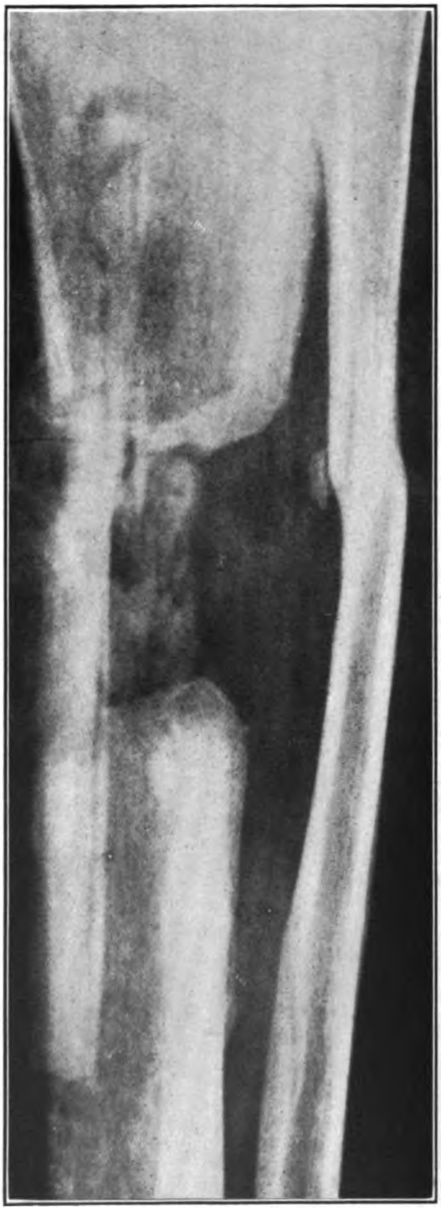


FIG. 163.—Case No. 27. Röntgenogram of repair of defect in the tibia by transplant from the opposite tibia, ten weeks after operation.

A röntgenogram, taken fifteen months after the original injury, shows no regeneration of bone in the defect (Fig. 162).

Transplantation of bone was performed, fifteen months after the original injury, to obliterate the defect in the tibia. The defect was exposed by a flap incision. The interposing fibrous tissue was removed. A gutter was cut into each fragment 5 cm. in length and 1.5 cm. in width. It was outlined with parallel motor saws. The sides of the gutter were cut on a bevel toward and into the medullary canal with a single motor saw. The ends were undercut on a bevel with a small motor saw. A transplant was removed from the internal surface of the opposite tibia. The periosteum was retained with it. It was made slightly longer than the gutter so that the ends would bind when in position. The sides and ends of the transplant were bevelled to fit the gutter. The transplant was introduced into the gutter, bridging the defect. It was secured to the fragments by the reverse bevels between it and the gutter. Kangaroo-tendon sutures were passed through holes drilled in the ends of the fragments and fastened around the transplant. The bone removed from the gutter was minced and placed in the defect. The wounds were closed by absorbable sutures. Both legs were immobilized by circular plaster-of-Paris casts.

A röntgenogram, ten weeks after operation, shows the transplant in position bridging the defect (Fig. 163).

2. EPIPHYSIAL DEFECTS.

Defects of long bones involving an articulation may be repaired by bone from the crest of the tibia. The transplant is grafted into the defect with the free end projecting into the articular space. As the transplant hypertrophies, it tends to form a bulbous extremity which makes a movable, useful joint, if the cartilage of the opposite articular surface has not been destroyed. Such a transplant will grow in circumference, but not in length, which is not of consequence in adults.

The upper end of the fibula with its joint surface furnishes a transplant with an epiphysis and a cartilage-covered, articular extremity, which in children will have a tendency to grow in length as well as in thickness.

EPIPHYSIAL DEFECTS OF SPECIAL BONES.

HEAD OF HUMERUS.—The shoulder, being an enarthrodial joint with a large, loose capsule, gives the best opportunity for joint repair.

The defect is exposed by Langenbeck's incision (Fig. 54). The extremity of the fragment of the humerus is developed and fitted for the reception of the transplant. If a transplant from the upper part of the fibula is used, the cut end is stripped of periosteum and wedged into the medullary canal of the humerus. The articular extremity is inserted into the glenoid cavity and the capsule of the joint sutured around it. The muscular attachments are sutured in place, the wound is closed, and the extremity immobilized to the body with plaster of Paris.

In a case reported by Rovsing,[38] a resection of the upper two-thirds of the humerus, including the epiphysis and articular surface, was performed for round-cell sarcoma in a machinist aged twenty-six years. The upper part of the fibula, including its epiphysis and articular surface, was transplanted into the defect.

At the end of two months the transplant had grafted solidly to the humerus, and the patient was using the arm with a movable functional joint (Fig. 164).

When a transplant from the crest of the tibia, with periosteum on two sides, is used, one end is bared of periosteum and forced into the medullary canal of the humerus and the other end is inserted into the glenoid cavity. The capsule is sutured around it and the muscles attached to the periosteum of the transplant.

In a case reported by Murphy,[14] a resection of the upper part of the humerus, including the epiphysis, was performed for osteitis fibrosis cystica in a girl aged ten years. Bone from the crest of the tibia, seven and a half inches long, seven-eighths inch wide and one-half inch thick was transplanted into the defect. The arm was dressed in abduction at a right angle to the body with weight extension.

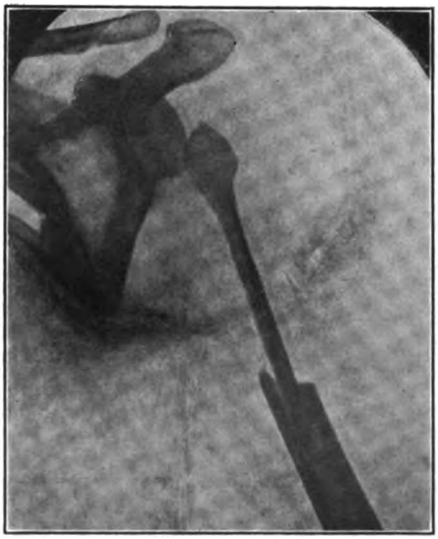


FIG. 164.—Röntgenogram of transplantation of the fibula into the upper two-thirds of the humerus, following resection for sarcoma. (Rovsing.)

At the end of five weeks the transplant had grafted to the humerus. There was good voluntary motion at the joint up to a right angle in abduction (Fig. 165).

ULNA.—The epiphysis at the inferior extremity of the ulna with its articular surface has been resected for sarcoma, by Bloodgood,[39] and the bone replaced by a transplant taken from the ulna at a point above the resection (Fig. 166).

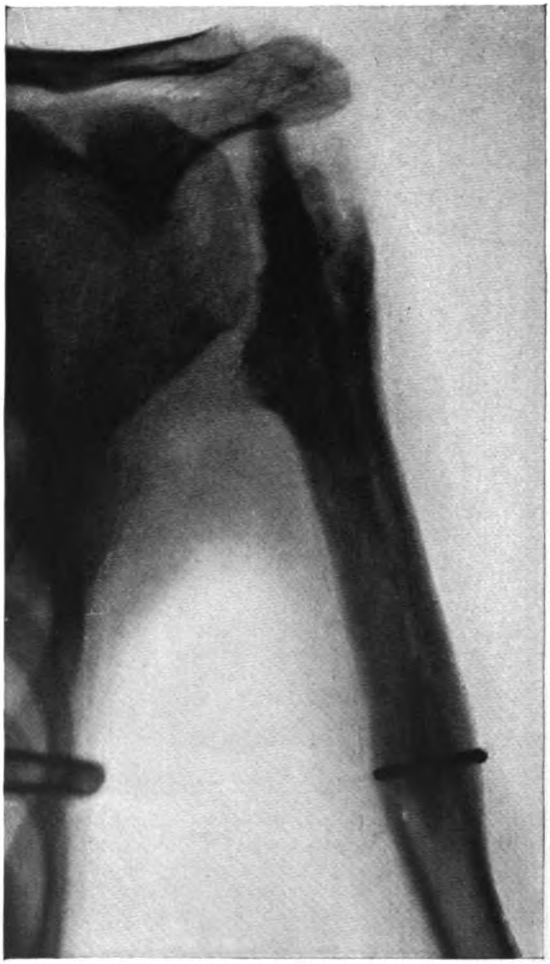


FIG. 165.—Röntgenogram of transplantation of bone from the tibia into the upper end of the humerus, following resection for cystic disease, nine months after operation. (Murphy.)

In three months the patient had recovered with good function of the wrist.

Phalanges.—Transplantation of bone to replace epiphyses in phalanges destroyed by disease has been performed by Haas,[34] with restoration of joint function.

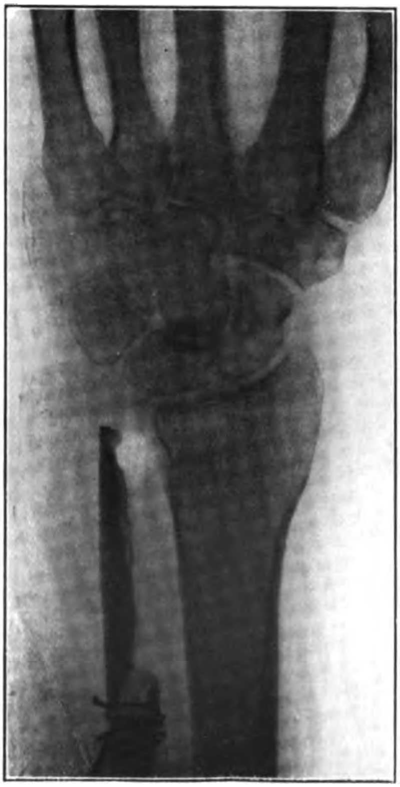


Fig. 166.—Röntgenogram of transplantation of bone from the tibia into the lower end of the ulna, following resection for sarcoma. (Bloodgood.)

Substitution of an entire phalanx from the toe with its epiphyses and articular surfaces intact, for diseased phalanges of the fingers, has been successfully performed by Wolff[40] and Gaebel.[41]

Head of Femur.—Murphy[14] resected the head, neck and upper part of the shaft of the femur for sarcoma in a man aged forty-one years. He transplanted bone from the tibia to fill the defect (Fig. 167). One year afterward there was considerable voluntary motion at the hip, but weight-bearing had not been allowed.

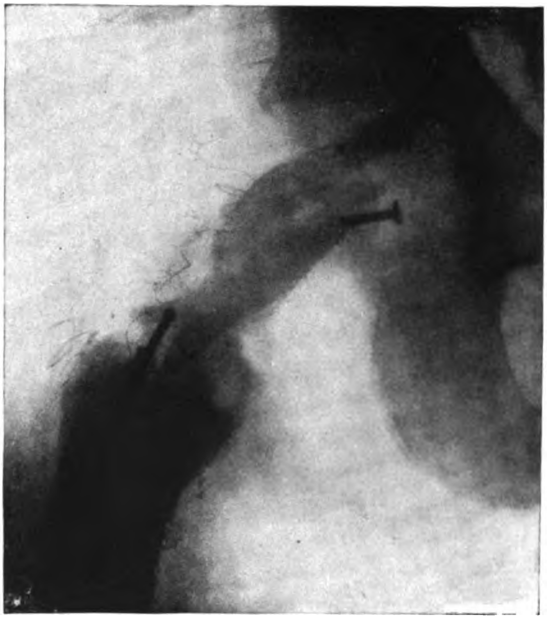


FIG. 167.—Röntgenogram of transplantation of bone from the tibia into the upper end of the femur, following resection for sarcoma. (Murphy.)

FIBULAR TRANSPLANT.—Following the lines of Rovsing's operation (Fig. 164) for repair of the head of the humerus, possibly the upper part of the fibula would make a better transplant for replacing the upper part of the femur. The fibula would furnish a transplant with an articular extremity and a body of sufficient size to wedge solidly into the medullary canal of the femur without need of fixation by a foreign body.

BONE TRANSPLANTATION IN KNEE-JOINT DISEASE.—Resection of the knee-joint, followed by transplantation of bone across the defects, has been recommended by Moszkowicz[42] and Enderlen[43] for sarcoma involving the epiphyses of both the femur and tibia, and by Albee[22] for tuberculosis of the same structures.

The transplant replaces the bone destroyed by the disease and resection, fastens the femur and tibia together by bony union, and establishes a stable extremity by the elimination of the knee-joint.

3. ACQUIRED NASAL DEFORMITIES.

Autoplastic remodelling of the bridge of the nose by the transplantation of bone to remedy the deformities produced by destruction of the bony framework by injury or disease has been employed with success by Carter,[44] Lothrop[45] and others.

The method of operation used by Carter consists in the elevation of the soft parts of the nose through an incision over the nasofrontal process and the insertion of a transplant taken from the cortical part of a rib to form a new nasal bridge.

A short, curved transverse incision is made over the nasofrontal process with the convexity downward. The skin and superficial tissues over the dorsum and sides of the nose are freed down to the bone, through this incision, by means of a long, thin, double-edged knife curved on the flat (Fig. 168). Through the same incision the periosteum is elevated for a short distance upward to receive the upper end of the transplant.

A segment of one of the lower ribs is obtained and a proper-sized transplant is shaped, its periosteum, endosteum and marrow removed, and the remaining strip of cortical bone is inserted into the bed prepared for it. The upper end is fixed by sutures under the periosteum at the nasal notch. The lower end supports the tip. The body of the transplant shapes the bridge of the nose.

The wound is closed by sutures and dressed with sterile gauze, which is allowed to remain for one week.

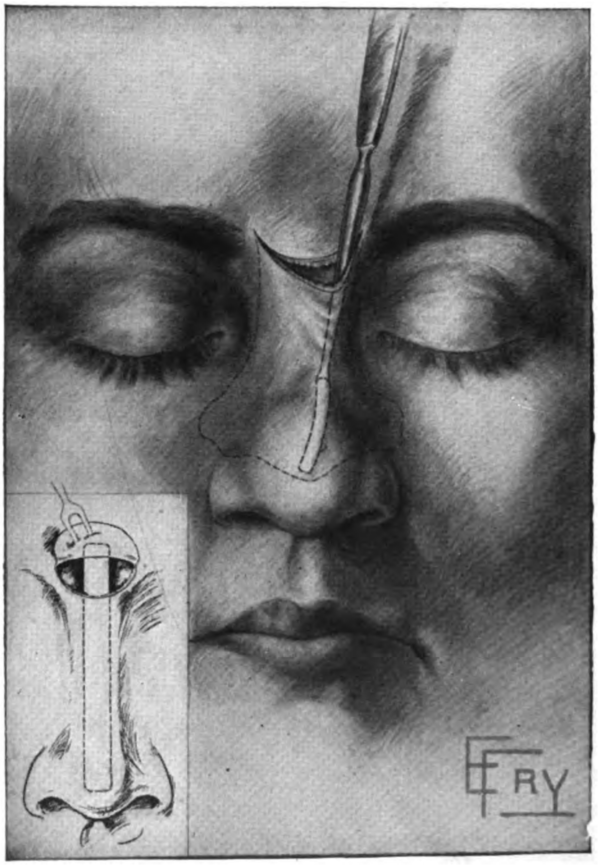


FIG. 168.—Transplantation of bone for nasal deformity. (Carter.)

The operation recommended by Lothrop differs in the origin of the transplant and method of insertion. Bone for transplantation is obtained from the vertebral border of the scapula. It furnishes a transplant already shaped, except in length and width, covered with periosteum on three sides.

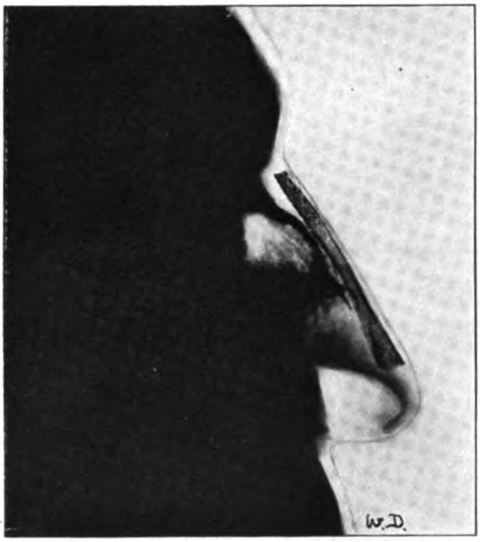


FIG. 169.—Röntgenogram (lateral view), showing the scapular transplant in position, grafted to the nasal bones and supporting the soft tissues of the nose. (Lothrop.)

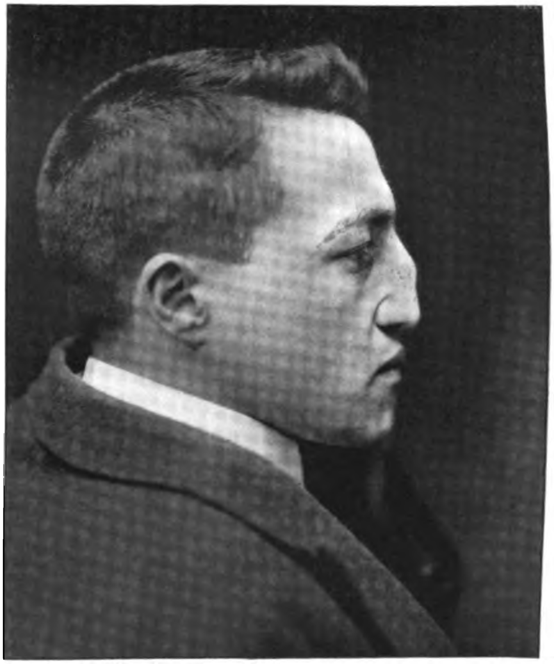


FIG. 170.—Nasal deformity (side view), before operation. (Lothrop.)

An incision in the under surface of the tip of the nose and a subcutaneous canal extending to the nasal bones is made. The periosteum of the nasal bones is elevated along the bridge of the nose up to the frontal bone. The nasal bones are shaped and smoothed down with a rasp until the transplant fits. The scapular transplant is fitted as to length, and placed with the freshly cut surface next to the nasal bones. It is inserted into the canal prepared for it under the periosteum until the frontal bone is reached (Fig. 169). The incision at the tip of the nose is closed by suture and covered with a collodion dressing. A dressing is applied to the nose, for four weeks, that exerts slight pressure on the upper end of the transplant to hold it in apposition to the frontal bone, and also supports the tip of the nose (Figs. 170 and 171).

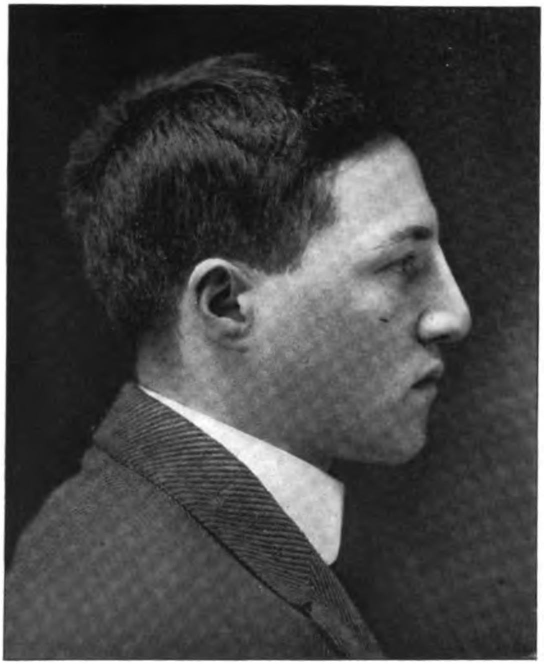


FIG. 171.—Nasal deformity (side view), after operation. (Lothrop.)

The scapular transplant, with three sides of natural bone surface covered by periosteum, is much more likely when grafted into position to retain its vitality and shape in its new relations, without absorption or overgrowth, than a sliver of cortical bone from the rib, without periosteum, buried in the soft tissues with only slight bone contact.

4. ACQUIRED CRANIAL DEFECTS.

Occlusion of cranial defects by autoplastic transplantation of bone to protect the brain from irritation or injury has been successfully employed by many surgeons. When recovery has occurred from an injury involving the destruction and loss of the entire thickness of a portion of the skull, leaving the brain covered only by the soft parts, autoplastic transplantation of bone should be performed to protect the brain from injury.

A flap including all tissues to the pericranium, considerably larger than the defect, with its base toward the circulation, is separated and reflected. The exposed dura and the edges of the defect are cleared of fibrous tissue.

A rabbet is cut in the edges of the bony defect down to the inner plate, wide enough to support the transplant.

Bone for transplantation is taken from the entire thickness of the flat part of the scapula, retaining the periosteum on both sides. The retention of the periosteum on the under surface of the transplant is necessary to prevent adhesions to the injured dura mater and overgrowth of the transplant into the cranial defect.

The transplant is shaped and fitted to the rabbet in the edges of the cranial defect. The periosteum is removed from that part of the under surface of the transplant which is to be in contact with the rabbet, so that there will be bone-to-bone apposition between the transplant and the skull.

The transplant is wedged into the cranial defect, supported by the rabbet joint and its superficial periosteum sutured to the pericranium (Fig. 172).

The wound is closed by absorbable sutures, dressed and protected by a plaster-of-Paris skull cap.

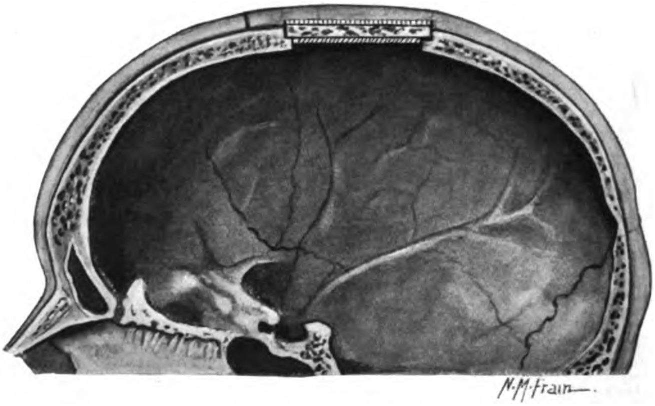


FIG. 172.—Scapular transplant in cranial defect.

The transplant closes the opening, grafts to the edges of the cranial defect and becomes an integral part of the cranium.

When the area of the whole thickness of the cranium has been destroyed and removed during an operation for depression, tumor or other disease of the skull, transplantation of bone to close the defect in the cranium by bone should be the final step of the operation, following the same technic as in occlusion of old defects.

When the cranial defect is long and narrow, bone from the outer table of the skull with its pericranium and superficial tissues may be separated from the immediate edge of the opening and grafted over the defect.[46] The transplant should be larger than the defect, so that it will rest on the edges and not cause pressure on the brain.

5. MANDIBULAR DEFECTS.

Autoplastic repair of defects of the lower jaw, produced by operation, injury or disease, has been attempted by Murphy,[14] Stillman[47] and others with varying degrees of success.

The causes of failure are: (*a*) difficulty of maintaining stable bony contact between the transplant and the jaw; (*b*) infection and suppuration around the transplant incident to the proximity of the mouth; (*c*) the intolerance of the bone of the lower jaw to operation when infected or undergoing partial sequestration.

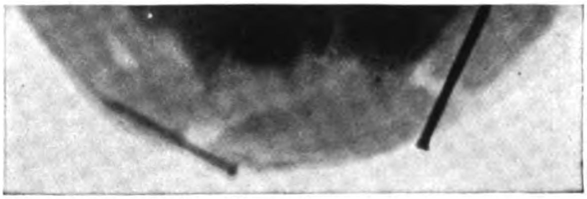


FIG. 173.—Röntgenogram of transplantation of bone into defect caused by gunshot wound of lower jaw. (Murphy.)

Murphy operated on a case of partial destruction of the lower jaw by a gunshot wound, causing a disfiguring deformity of the chin.

A flap was raised by an incision under the chin, exposing the defect in the bone. A transplant one and one-half inches long, one-half inch wide and three-eighths inch thick was removed from the tibia, shaped to fit the defect and to obviate the deformity. It was nailed in position. The wound healed by primary union and the transplant grafted to its new location (Fig. 173).

CHAPTER XI.

SPONDYLOLISTHESIS.

THE treatment of spondylolisthesis by autoplastic transplantation of bone, consists in the reduction of the deformity and in grafting of a tibial transplant to the vertebral column across the defective joint. It is attached to the lumbar vertebræ on the one side and the sacrum on the other, fixing the bones in their normal relationship by indirect ankylosis. The operation is similar to Albee's fixation of the spine for tuberculous spondylitis, except that it is modified by the condition of the vertebral spines in the vicinity of the lumbosacral articulation.

Ryerson[48] reported a case of recurrent spondylolisthesis successfully treated by this method. The patient was a strong, healthy girl, aged fifteen years, in which the recurrent displacement of the lumbosacral articulation was accompanied by pain and spastic paraplegia at each recurrence. The fifth lumbar vertebra could be felt to slip on the sacrum during flexion and extension of the back. A tibial transplant, long enough to reach from the third lumbar to the third sacral vertebra, was grafted across the defective joint.

The ultimate result was a strong fixation of the articulation, without any symptoms referable to the original difficulty.

SEPARATION OF THE SACRO-ILIAC SYNCHONDROSIS.

The treatment of this condition by autoplastic transplantation, consists in the grafting of bone into the sulcus between the posterior part of the ilium and the sacrum. The transplant bridges the space and produces an osseous fusion of the sacrum and ilium immediately posterior to the sacro-iliac synchondrosis, producing ankylosis of the articulation.

The treatment of this lesion by transplantation of bone is illustrated by the following personal case:

CASE No. 28.—Separation of the right sacro-iliac synchondrosis.—V. Z.; Hungarian; tinner; aged forty-one years; entered the University Hospital suffering with pain at the right side of the sacrum. He began to have pain fifteen years ago while a miner in Alaska. At times he carried packs weighing one hundred and fifty pounds for many miles over rough country. The pain was aggravated by stooping and bending to the right. A röntgenogram showed very appreciable separation between the sacrum and ilium on the right side.

Transplantation of bone was performed to produce ankylosis of the articulation. A posterior flap incision through the tissues down to the bone was made. The posterior sacro-iliac ligament and the periosteum were reflected from the space between the ilium and sacrum, posterior to the synchondrosis. The right synchondrosis was exposed. The articulation showed movement between the ilium and sacrum on flexion of the body. A transplant 7 cm. in length was removed from the crest of the tibia. It was forced into the sulcus between the sacrum and the ilium. The same amount of bone was minced and packed against the transplant. The pelvis was immobilized by a plaster-of-Paris body cast for eight weeks. A satisfactory recovery resulted.

FLAT-FOOT.

Katzenstein[49] treats intractable flat-foot by means of a new ligament built by the transplantation of periosteum across the weakened tarsal joints.

The bones adjoining the relaxed articulation are exposed and denuded. A strip of periosteum is obtained and folded lengthwise, turning the osteogenetic side inward, leaving it exposed only at the ends (Fig. 174). These ends are secured to the bone to insure grafting at these points. There is no further contact between bone and the osteogenetic surface of the periosteal transplant. The foot is immobilized for seven weeks.

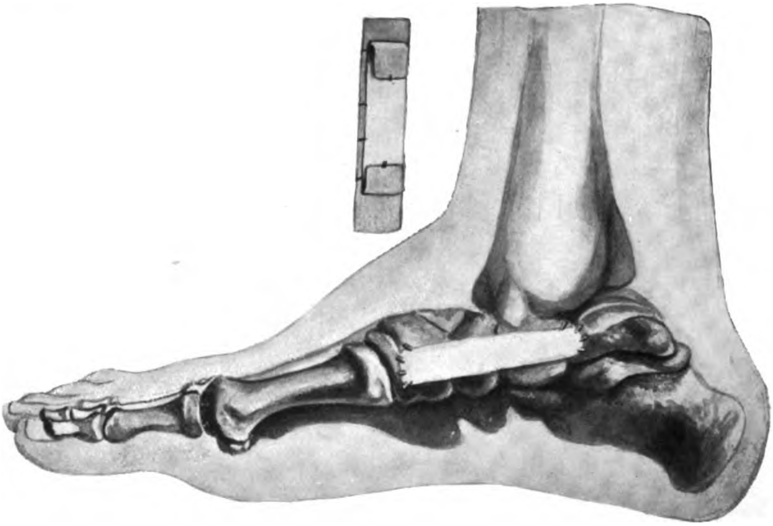


Fig. 174.—Formation of new ligament by a periosteal graft in flat-foot. K

Katzenstein has treated several cases in this manner, in each of which all functional disturbance was corrected at once.

ARTHROPATHY.

1. Knee-joint.—Ankylosis of the knee-joint has been recommended in infantile paralysis, and a series of successful cases reported by Hibbs.[50] The patella is mortised between the ends of the tibia and femur to prevent deformity and obtain function of the extremity without the aid of apparatus.

The knee-joint is opened and a space prepared for the patella anterior to the centre of the joint by removing cartilage from the tibia and femur. The cartilage is removed from the articular surface of the patella but the periosteum is preserved. The patella is wedged horizontally into the space prepared for it between the bones. The periosteum is sutured to the periosteum of the tibia and femur. The wound is closed and the extremity immobilized.

The patient is allowed to walk in from four to six weeks, supported by a plaster-of-Paris cast. All support is removed in from four to seven months.

When the patella has grafted into position, a strong, bony bridge is formed, producing permanent ankylosis of the knee-joint.

2. Ankle, Tarsal and Vertebral Joints.—Ankylosis of the ankle and tarsal joints to prevent deformity due to infantile paralysis can be accomplished by grafting a transplant across the articulation.

As an aid to other orthopedic operations for the restoration of the function of an extremity affected with infantile paralysis, this transplantation is valuable.

Paralytic scoliosis has been successfully relieved, as reported by Galloway, by the indirect ankylosis of the vertebral column. With the deformity corrected, a transplant is grafted to the spines of the vertebræ involved. By this method the spinal column may be stiffened in the direction required to overcome the scoliosis.

RECURRENT HERNIA.

Reinforcement of a relaxed or deficient abdominal wall by transplantation of bone may be performed as a step in the radical operation for inguinal or femoral hernia.

Under these conditions Trendelenburg transplanted a pedunculated flap of bone and periosteum chiselled from the symphysis. He inserted the transplant, 4 cm. long, 3 cm. wide and 3 cm. thick, into the inguinal or femoral canal. His results were successful.

Greene[51] did a free transplantation of fragments of a rib in a radical operation for a large, relaxed femoral hernia. Two inches of the eleventh rib were resected subperiosteally and split in half. The transplants were inserted perpendicularly into pockets made in the periosteum at the back of the pubic bone.

The hernia was relieved. Röntgenograms and palpation showed that the transplant was persistent at the time of the report.

McWilliams[52] transplanted a piece of a rib into the inguinal canal to strengthen a hernial repair. The transplant was not covered with periosteum and was not placed in contact with the skeleton. A röntgenogram, taken four months later, showed that the rib had entirely disappeared.

Periosteum should be retained on the transplant and it should be contacted, beneath the periosteum, to the symphysis pubis, to assure permanence of the transplanted bone.

TRIFACIAL NEURALGIA.

Kanavel[2] reported one case of transplantation of bone to close the infra-orbital foramen and the inferior dental canal for neuralgia.

The patient was a woman, aged seventy-four years, suffering with intractable facial neuralgia. She was in a condition of health which precluded an intracranial operation. Under local anesthesia the infra-orbital nerve was exposed and avulsed at the infra-orbital foramen. The periosteum was curetted from the canal and foramen and a small transplant, three-fourths of an inch in length, taken from the tibia, was wedged into the opening. The inferior dental canal was exposed at the angle of the jaw with a small trephine. The nerve was avulsed, the periosteum removed and the canal broken down. The button, removed by the trephine, was rotated and driven back into the opening, obliterating that part of the canal.

The patient was relieved of the neuralgia and remained well for nine months, during the interval of observation.

DEFORMITY OF THE FEMALE PELVIS.

Smith, F. D.,[3] proposes the following operation for transplantation of bone into the symphysis pubis, increasing the diameter of the female pelvis, to relieve mild cases of dystocia.

Incision is made over the pubis, the symphysis is spread and the interpubic fibrocartilaginous tissue completely removed. The nipple-like projections are curetted until the bone is entirely bared. The pubic bones are forcibly spread apart until the required increase in diameter of the pelvic outlet is attained. A transplant, measured by calipers, to fill the space between the pubic bones, is taken from the internal surface of the tibia. The periosteum is retained on it. The transplant is mortised into the pubic bones and wedged into position. It is fastened by strong strands of kangaroo tendon passed through holes drilled in both the transplant and the pubic bones. The pelvis should be immobilized by plaster of Paris until the transplant has grafted solidly into position.

The description of this operation is based entirely upon animal experimentation since, as yet, no reported cases have appeared where it had been performed on the human pelvis.

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